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GAS ENGINE FACTS

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GAS ENGINE
FACTS

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FOREWORD

When Gas Review was started in January 1907 we arranged to publish a series of easy lessons on the gas engine under the heading Gas Engine Course.

The first twenty-eight of these lessons were published in 1910 in a little book called Gasology. This book had a wide distribution and so many people have asked to have the remainder of the lessons put up in book form that we decided to do so.

These lessons are of necessity somewhat fragmentary. Each lesson is complete in itself and yet is related to the one that goes before, though not as closely as would be the case if they had been written primarily for book use. This is, of course, a deftct, but one we trust our readers will be charitable enough to overlook when they consider the necessary limitations imposed in magazine articles.

We make no claim that the various subjects touched upon have been fully discussed. That was not our intention. All we have tried to do is to present the most important subjects as concisely as possible and give as much information as possible in a limited space. At the same time we have tried to make the lessons easy to understand.

Part of Chapter VII and all of Chapter VIII may appear rather difficult reading for the average person, but there were so many requests for a discussion of the chemistry of combustion and the theory of heat, in so far as it applied to the matter of compression pressures and temperatures, that we included these discussions in the lessons.

No claims are made for originality other than in the matter of general simplicity and phraseology. We trust this little book may have as cordial a reception as its predecessor Gasology.

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GAS ENGINE FACTS

CHAPTER I.

SOME FEATURES OF GAS ENGINE DESIGN.

LESSON I.

The indicated horse power of an internal combustion engine is a measure of the actual horse power developed in the engine cylinder. It is, in other words, the power that is expended upon the piston and is always considerably greater than what can be obtained from the engine in useful work at the fly wheel. When the fuel and its proper proportion of air is introduced into the engine cylinder and burned it produces a very high temperature of the gas behind the piston. In accordance, therefore, with the laws of heat, this gas, which is at the given instant enclosed in a small space, exerts tremendous pressure upon the walls of the cylinder and upon the head of the piston. In the case of ordinary gasoline engines this pressure, at the moment the piston starts forward on its power stroke, may amount to from 250 to 300 pounds per square inch.

The exact amount of the initial pressure is dependent upon a number of things, among which may be mentioned the degree of compression of the charge, the temperature of the gas at the moment of ignition, the degree of completeness of the combustion before the piston starts forward on its power stroke, and the quality of the mixture.

If the gas is first compressed to 60 or 70 pounds and the fuel is capable of raising the pressure 200 pounds, the total initial pressure will be the sum of the two. Consequently the higher the compression pressure with any given fuel, the higher will be the initial pressure; and, within certain limits, the greater the power of the engine. It has been stated in nearly every book treating of the gas engine that its efficiency depends very largely upon the degree of compression. It can be proved theoretically that the higher the degree of compression in the case of any engine working on the Otto cycle, the greater the efficiency. This means that with the expenditure of a given quantity of fuel the greatest amount of work can be obtained when the compression is carried to the highest point possible. This is true, regardless of the kind of fuel used. Practically, the kind of fuel exerts a marked influence because of the fact that compression cannot be carried as high with some kinds of fuel as with others. For example, gasoline vapor is highly inflammable and will ignite at lower temperatures than some other gas, such as blast furnace gas or producer gas.

In ordinary medium speed gasoline engines a compression pressure of 70 pounds is about as much as can be obtained without causing preignition. If the engine is of the slow speed type, compression pressures as high as 80 or 85 pounds are often carried successfully, while with the high speed automobile engines a compression of 60 pounds is customary. It requires, therefore, no stretch of the imagination to realize that an engine suitable for one kind of fuel may not be suitable for another. Furthermore, an engine that will produce a given amount of power with one kind of fuel may be very inefficient and lack a great deal of coming up to its power specifications when another kind of fuel is substituted. This can be explained easily when we take into consideration the heat values of some of the different fuels.

Gasoline vapor has a heat value of about 650 heat units per cubic foot; producer gas from 90 to 125; city gas 750 to 900; and natural gas from 1,000 to 1,100. An engine, therefore, which uses a gas of high heat value, such as natural gas, will yield considerably more in horse power than the same engine using producer gas, for the simple reason that the gas containing the larger number of heat units contains the greater amount of energy which may be set free for the doing of useful work.

The degree of completeness of combustion before the piston starts forward on its power stroke has much to do with the initial pressure. To be most effective, the fuel should all be consumed before the piston has advanced an appreciable amount on its power stroke. When this condition obtains, the initial pressure will be the maximum for the given charge of fuel, and the piston will be driven forward by the expansion of the gas solely and not by the addition of more pressure due to what is known as after-burning. It can also be shown theoretically, and it has been proven practically that the best results are obtained when the fuel is all burned at the beginning of the stroke and the expansion is adiabatic. That is, when no heat is either supplied or taken away during the stroke. It naturally follows from the construction of the engine and its method of operation that a true adiabatic expansion cannot be obtained. There will be some transfer of heat from the gas to the cylinder walls at the beginning of the stroke and toward the end of the stroke there may be a flow of heat in the opposite direction, all of which has a tendency to reduce the rmal efficiency of the engine.

The quality of the mixture is another matter of importance in connection with the efficiency and power of a gas engine. If the mixture is rich in fuel gases, that is, if it contains a large quantity of heat units it cannot be compressed as high as a leaner mixture, and consequently its efficiency will be reduced. Almost any gas, no matter how lean, if compressed high enough, can be ignited, and, in view of the statement that efficiency depends upon the degree of compression, it would thus appear that lean mixtures yield the higher efficiencies. This appears to be true theoretically and has been worked out and verified practically.

We made the statement that the power which might be obtained at the fly wheel is always less than that expended upon the piston. This is true in the case of the steam engine but more particularly true of the gas engine. The difference between the power supplied to the engine and that which may be obtained from it, is used up in internal friction. In the case of the steam engine there is the friction of all the working parts which may amount to anywhere from five to twenty per cent of the power supplied. In the case of the gas engine the friction is considerably higher, due to the fact that for every four strokes of the engine there is only one power stroke. There must be supplied by the fuel a certain extra amount of power to overcome the friction of the three idle strokes, thus making the difference between the indicated and brake power much larger than in the case of the steam engine. The very highest efficiency obtained from gas engines shows a loss of at least fifteen per cent in friction, while losses of twenty and twenty-five per cent are common and represent current practice.

The mechanical efficiency of an engine is represented by the ratio between the brake horse power and the indicated horse power; for example, if an engine indicates 5-horse power and it shows 4-horse power by brake test at the fly wheel, its mechanical efficiency is four-fifths or eighty per cent.

The thermal or heat efficiency, however, is a different thing and represents the proportion of the heat energy which is transformed into mechanical energy. This is always low and for ordinary medium sized gas engines is in the neighborhood of fifteen per cent. In a few cases thermal efficiencies as high as twenty-five per cent have been obtained for gasoline engines, while the very highest efficiencies have amounted to about thirty per cent. Where the thermal efficiency is twenty-five per cent it means that the heat value of one hundred pounds of fuel is utilized or expended in the engine to obtain the useful effect of only twenty-five pounds. There is, then, a loss of three-fourths of the heat energy supplied to our best gasoline engines in transforming the fuel into useful energy.

LESSON II.

In our last lesson we showed that there was a great deal of difference in the amount of heat contained in a cubic foot of different kinds of fuel ranging from about one hundred heat units for producer gas to as high as eleven hundred heat units for natural gas. It was also pointed out that that gas which contains the greatest quantity of heat is capable, under favorable circumstances, of doing the greatest amount of work. It is evident, therefore, that an engine whose dimensions are such as to yield a certain horse power with one kind of fuel, might fall far short of or exceed it with another. An engine must, therefore, be designed expressly for the kind of fuel it is expected to use. While it may run fairly well on some other kind of fuel it cannot be expected to yield as good efficiency or even develop the same amount of power. There must be a difference both in the cylinder dimensions and in the amount of compression for the same power developed. For example, it would be unreasonable to expect an engine running on a lean fuel like producer gas to yield as much power for certain cylinder dimensions as one that uses a rich gas like natural gas or gasoline. Again take the matter of compression, a slow s ed engine working on producer gas may work under a compres- pressure of anywhere from one hundred and fifty to two hun- ea and fifty pounds, while a high speed automobile engine using line for fuel will not give satisfactory service with compression much above seventy pounds.

Rated Horsepower	Bore	Stroke	R.P.M.	Total wt. of machine	Weight per horsepower	Horsepower computed by Roberts' formula.
3	4½	7	400	300	100	3.15
3	5	6	400	1200	400	3.33
3½	4¾	6	400	—	—	3.08
5	6	7	360	1350	270	5.04
5	5½	6	400	—	—	4.03
5	5¼	8	375	1570	314	4.60
5½	6	6¾	375	650	118	5.06
6	5	6	400	700	116	6.66
7	6	8	350	—	—	5.60
7	6	8½	350	1950	278	5.95
7	6¾	8	300	1900	271	6.07
8	5¾	6¾	375	850	112	9.38
9	7	10	320	—	—	8.70
10	7¼	8	350	—	—	8.17
10	7½	10	275	2500	250	8.59
12	7¼	11	300	3900	325	9.64
12	6½	7½	325	1600	133	11.44
12	7½	8	350	—	—	8.75
13	8½	12	250	3400	261	12.02
15	7¼	8¼	300	2500	166	14.40
15	8¼	12	280	4980	332	12.68
16	9½	12	250	3600	225	15.04
18	8¾	13	280	5700	316	15.40
20	8¾	10¼	300	3500	175	26.16
35	10½	11	300	11000	314	38.20
55	12½	13	275	14000	254	58.80

TABLE I.

Then there is the weight of engines per horse power to be considered. Here is a subject that evidently will bear much investigation. Some engines are extremely heavy while others, like automobile and aeroplane motors, are exceedingly light, running as low as two pounds per horse power for some of the latter. Take it all in all, it is not easy to make a comparison of different engines even where designed for the same kind of work and using the same kind of fuel.

As illustrating the difference in designers' ideas, a table of cylinder dimensions, horse power and engine weights is given in Table I. This information is based on reports just recently received from a number of manufacturers. We asked, in the case of horse power, for the maximum brake horse power, but an inspection of the figures leads us to believe that we were given the manufacturers' ratings instead. Even if this is the case, as we strongly suspect, it shows that there is a wide diversity in rating. The matter of speed, compression, and minor points of design complicates the matter considerably and makes a true comparison difficult. The engines specified in the table are all gasoline engines except the two largest ones, and so we were enabled to apply the same horse power formula to all of them. We used Robert's formula, which is as follows for gasoline engines:

$$\frac{D^2 \times L \times R \times N}{18000} = \text{H. P.}$$

D^2 represents the diameter of the cylinder in inches; L, the length of stroke in inches; R, the number of revolutions per minute and N, the number of cylinders.

While the engine may yield either more or less power than computed according to the formula, the formula nevertheless gives comparative results since it takes into account the various factors of cylinder dimensions and speed which, for engines working with the same compression, are the fundamental factors. If the compression varies among the various engines, the formula would not, of course, give true comparative values. In the cases we have been considering, however, the compression is practically the same and amounts in almost every case to sixty pounds. With higher compressions, up to about one hundred pounds, the power would be increased slightly, but the dangers of pre-ignition would be increased as pointed out before.

An inspection of the table reveals some rather startling discrepancies, discrepancies, by the way, that can only be explained on the basis of unsystematic design. We mean by this in not following any definite method in rating the horse power of the engines. The smaller engines are up to standard, but those of the larger size fall below their rating if we assume the same values as hold in the small sizes. This is especially noticeable in those engines of 8- and 12-horse power.

The ratio of bore to stroke is another thing that has not been very carefully standardized. The table shows a variation of from one and two-tenths to one and four-tenths. The tendency of modern designers is to make the ratio of stroke greater than it was some three or four years ago. The best modern engines below 1,000 revolutions per minute have ratios of less than one and three-tenths. Slow speed engines are frequently built with ratios as high as two, but this appears to us to be going to the other extreme.

There is one other matter shown in the table that deserves some attention and that is the matter of weight per horse power. This varies from one hundred pounds to four hundred pounds. We do not presume to say which is correct, but it seems to us that there is too great a discrepancy. We can see no very good reason for such a wide difference.

LESSON III.

Table II, which we are printing with this lesson, shows the proportions found in ordinary gasoline engines. This table was made up from replies to an inquiry sent out to a large number of manufacturers of small gasoline engines, and consequently represents current practice. It might be mentioned in passing that the large engines above 35-horse power are designed to use gas for fuel.

The first thing to attract attention is the thickness of the cylinder walls. It must be understood that the tendency of modern design and of correct design is to the economy of materials and to the placing of this material in the places where it is needed to give proper strength and stiffness to the completed structure. In the cylinder stresses are due to the force of the explosion, or the pressure generated by the gases formed during the burning of the charge and to difference in temperature between the inner and outer walls. Of these two forces, that due to the pressure of the gases is the greatest and is the one that is considered in all computations regarding the strength of the cylinder. Temperature stresses are taken care of by introducing a very high factor of safety. The strength of the material, which is cast iron, used for cylinder construction, varies in tensile strength rom twenty thousand to twenty-four thousand pounds. It is usual consider three thousand pounds as the allowable working stress, us providing for a factor of safety, as it is often wrongfully termed, or between six and eight. The extreme pressure supposed to come upon the cylinder walls is taken at five hundred pounds. In all formulas for the strength of cylinders, the stress is obtainable by multiplying the pressure to which the cylinder may be subjected, in pounds, by one-half of the diameter, expressed in inches. If this stress be then divided by the allowable working stress the quotient will be the thickness of the cylinder walls in inches to withstand the given pressure. Expressed in a formula this would be as follows:

Rated horse power	Bore	Stroke	Thickness of cyl. walls	Depth of water space	Thickness jacket walls	Length of con. rod	Dia. piston pin.	Dia. C'k pin	Width of crank pin	Dia. Main journal	Length of main jrnl.	Dia. fly wh'ls	Wt. fly wh'ls	Dia. inlet valve stem	Dia. inlet valve	Dia. exh. valve	Dia. exh. valve stem	Total wt. of engine
3½	4¾	6	—	—	—	15	1⅛	1⅝	1⅞	1 11/16	8¼	—	220	—	1⅜	—	—	—
5	5½	6	—	—	—	15	1⅛	1 15/16	1⅞	1 15/16	8¼	—	330	—	1⅜	—	—	—
7	6	8	—	—	—	19¾	1½	2¼	2½	2¼	11½	—	560	—	1⅞	—	—	—
10	7¼	8	—	—	—	19¾	1½	2½	2½	2 9/16	11½	—	900	—	2	—	—	—
12	7½	8	—	—	—	19¾	1½	2½	2½	2 9/16	11½	—	1100	—	2	—	—	—
3	5	6	—	—	—	—	—	2	2	2	4½	30	300	—	2¼	2¼	—	1200
5	6	7	—	—	—	—	—	2¼	2¼	2¼	5	34	400	—	2¼	2¼	—	1350
7	6¾	8	—	—	—	—	—	2¾	2½	2¾	6	38	600	—	2¾	2¾	—	1900
10	7½	10	—	—	—	—	—	3	2¾	3	6¼	44	850	—	2¾	2¾	—	2500
13	8½	12	—	—	—	—	—	3½	3½	3¼	6¾	50	1100	—	3½	3½	—	3400
16	9½	12	—	—	—	—	—	3½	3½	3¼	6¾	51	1300	—	3½	3½	⅝	3600
5½	6	6½	½	—	⅜	12½	1⅛	2¼	2½	2⅛	5½	32	244	½	2⅜	2⅜	½	650
6	5	6	½	—	⅜	9½	⅞	1⅞	2	1¾	4	26	310	½	1¾	1⅞	⅝	700
8	5¾	6¾	½	—	⅜	12½	1⅛	2¼	2½	2⅛	4⅛	28	370	½	2⅜	2⅜	⅝	850
12	6½	7½	½	—	⅜	15	1¼	2⅝	3	2⅝	5½	42	790	⅝	2 11/16	2 11/16	⅝	1600
15	7½	8½	⅝	—	7/16	15½	1¼	3	3¼	3	5½	40	1090	⅝	2 15/16	2 15/16	⅝	2500
20	8½	10½	⅝	—	7/16	20	1½	3½	3¾	3½	7	46	1460	⅞	3⅝	3⅝	⅞	3500
8	6½	10	⅝	¾	⅜	24½	1⅜	2 7/16	2 7/16	2 7/16	4 23/32	35½	370	½	2½	2½	9/16	1700
46	10½	15	—	2	—	—	3½	5½	5	5½	12½	67	2400	1	3¾	3¾	1¼	13000
3	4½	7	—	—	—	15	1⅛	—	1¾	1¾	5 7/16	24	270	—	—	—	—	800
5	5½	8	—	—	—	17	1¼	—	2⅝	2⅝	6	32	580	—	—	—	—	1570
7	6	8½	—	—	—	18	1½	—	2½	2½	6½	36	720	—	—	—	—	1950
9	7	10	—	—	—	25	1⅞	—	2¾	2¾	7¼	42	1060	—	—	—	—	
12	7½	11	—	—	—	26	1⅞	—	3¼	3¼	5¾	50	1240	—	—	—	—	3900
35	10½	11	1 1/16	1	7/16	33	3⅝	5	4¾	4¾	—	60	3000	13/16	3½	3	13/16	11000
55	12½	13	1¼	1⅛	½	39	4¼	5¾	5½	5¾	—	64	4000	⅞	4¼	3½	⅞	14000
75	14½	16	1¼	1¾	½	47	5	6½	6¼	6½	—	73	6000	1	4¾	4	1	20000
100	16	16	1⅜	1½	⅝	47	5½	7¼	7	7¼	—	73	7000	1¼	5⅛	4⅝	1¼	25000

TABLE II.

$$\frac{P \times R \times 6}{Ts} = \text{thickness of metal.}$$

In this formula P is 500 and Ts is 20,000, R is the radius of the cylinder and 6 is the factor of tensile strength permissible. Applying this to the 5½-horse power engine we obtain the following figures:

$$\frac{500 \times 3 \times 6}{20{,}000} = 9/20 \text{ of an inch}$$

or just under one-half an inch. This shows that the walls of this cylinder are correctly proportioned, since the designer has taken the next value above that worked out by the formula. Let us now apply the same formula to the 20-horse power engine, and we arrive at the following figures:

$$\frac{500\times4\frac{3}{8}\times6}{20{,}000}=.656$$

or just a trifle more than five-eighths of an inch. This cylinder is probably strong enough but it is not quite as safe as the first one considered. The cylinders of the large engines all appear to be designed in accordance with the formula. It is by no means certain that pressures exceeding five hundred pounds per square inch may not at times be attained in the cylinders of gasoline engines, especially in cases of pre-ignition. In such cases, of course, the factor of safety is much less than six, but still if there are no flaws in the metal there is sufficient excess strength to withstand the added strain. If the metal is homogeneous and will actually bear a stress of twenty thousand pounds before giving way, a six-inch cylinder would bear a pressure of three thousand pounds before bursting. The metal of which gas engine cylinders is composed is cast iron, but it must be of specially fine close grained grade which will bore out smooth and take a high polish. This is obtained by a judicious mixing of different grades of iron in the foundry cupola.

Some writers make the statement that since there is no pressure on the jacket walls it is not necessary to make computations in regard to their thickness and that the only considerations involved are those of casting thin pieces. The statement is also made that walls less than one-quarter of an inch thick cannot be cast without considerable difficulty and this is given as the limit of thinness. Jacket walls which are cast integral, that is, as a part of the cylinder, are subject to a tensile strain the same as the rest of the cylinder during the explosion and compression of the gases. It is also subjected to a bending force due to the side thrust of the piston. It is possible to compute the value of these forces and to devise a formula which will give the proper thickness of metal to take care of them. Such a formula has been submitted by Guldner and reads as follows:

$$S=\frac{D^2}{20Dm}$$

in which S represents the thickness of the jacket wall; D the bore of cylinder; and Dm the mean diameter of the jacket. Applying to the 8-horse power engine in Table II and inserting numerical values in the formula, we arrive at the following results:

$$\frac{6\frac{1}{2}\times6\frac{1}{2}}{20\times8\frac{3}{8}}=.26 \text{ of an inch.}$$

The designer has used three-eighths of an inch and therefore is on the safe side by a wide margin of safety. Guldner also states that the jacket walls should not be less than seven-sixteenths of an inch thick for small engines nor nine-sixteenths for large ones. There is no good reasons for these limitations aside from the difficulty of obtaining sound thin castings. There are many small engines built with jacket walls only one-quarter of an inch thick which give no particular difficulty in the foundry.

There seem to be no rules published regarding the depth of the water space. In small engines of 1 to 2-horse power it is made as little as one-quarter of an inch. In engines of 10-horse power, from three-eighths to one-half an inch is a common dimension. Larger engines require larger water spaces as shown in the table, but there seems to be no generally recognized law of increase corresponding with the increase in power. Some small engines using the hopper cooling system, whereby the water is boiled away instead of being circulated, use fully as large water spaces as the large engines shown in the table. This is necessary because considerable water is necessary and space must be provided in which it may be retained. At the same time all of the inner surfaces must slope smoothly and gradually up to the hopper so that no pockets may exist in which steam may form and drive out the water.

CHAPTER II.

METHODS OF COOLING THE CYLINDER.

LESSON IV.

A British thermal unit, or, merely a heat unit as it is generally called, is equivalent to 778 foot pounds of work. Consequently 1-horse power, or 33,000 foot pounds, is equivalent to 42.4 heat units. The amount of heat needed per horse power per hour is therefore 42.4×60 or 2,544 heat units. We usually say it requires the expenditure of 2,550 heat units per horse power per hour, thus using approximate figures. Now it is a good average gas engine that will yield twenty per cent efficiency, that is, for every horse power actually developed it requires that 5-horse power be supplied in the form of fuel energy. Translated into figures this means that for every horse power developed 2,550×5 or 12,750 heat units must be supplied. Only 2,550 are turned into useful work and the remainder goes to waste. The greater part of this heat either escapes with the exhaust gases or with the jacket water. Of the two, the latter is credited with the more. Experiments have shown that roughly one-third of all the heat supplied to a gas engine finds its way into the cooling medium without doing any useful work. Knowing this, we can discuss the design of the cooling system with more intelligence.

From the foregoing it is clear that the cooling medium must be designed to absorb at least one-third of the total amount of heat supplied to the engine without passing certain comparatively low limits of temperature. In the case of water this limit is two hundred and twelve degrees—the boiling point at atmospheric pressure. Where oil is used, the upper limit is the boiling point of oil under atmospheric pressure, which is somewhat higher than that of water.

Experiments with hopper cooled engines using water show that it requires just a little more than four-tenths of a gallon of water per horse power hour. This water escapes in the form of steam at atmospheric pressure and carries away a large amount of heat, for in addition to the heat required to bring the water to the boiling point there is the latent heat of vaporization to be accounted for, which amounts to fully five times what is required to merely heat the water o the boiling point. Starting with water at seventy degrees Fahrenheit, each pound of water turned into steam carries away 1,108 heat units. This large heat content accounts for the relatively small amount of water used in this method of cooling.

For small stationary or portable engines the method works very satisfactorily and has the advantage that it does away with the necessity for a circulating pump and a separate cooling tank or other device. But it has certain disadvantages that will readily occur to any one who considers the matter for a moment seriously. There is the cloud of steam that rises continually and which may be more or less of a nuisance in a closed room, especially where other bright parts of machinery may be installed. The steam, of course, would cause rusting. For large installations this would be a serious objection. Then again an engine so equipped will not work at its most economical rate until the water gets near to the boiling point as the cold water will keep the cylinder too cold and absorb heat energy that might be turned into useful work. In an engine working under full load it does not take very long for the water to get hot.

Perhaps the system requiring the least replenishment of water is that used on automobiles where a circulating pump is used and the water is forced through a radiator and cooled without the formation of and loss of steam. This is a relatively expensive system and one not well adapted to cheap, simple engines on account of expense and the difficulty of caring for the radiator.

Another scheme is the use of a cooling tank containing a large reservoir of water which is connected with the cylinder by means of two pieces of hose. The cylinder is placed near the bottom of the tank and the level of water in the tank is above the upper hose connection. The cylinder, being the source of heat, acts just like a furnace in a hot water house heating plant, causing the water to circulate at a slow rate of speed through the cylinder jacket. This system is bulky and has given way in the last few years to better methods of cooling. Where it is used, Guldner gives the following formula for determining the size of the cooling tank:

$$v=1.4zN \text{ cu. ft.}$$

In this formula v represents the capacity of the tank in cubic feet; z the hours daily the engine is in use and must be equal to or greater than ten; N is the brake horse power. It is recommended that the height be made from 1.75 to 2.50 times the diameter. Such tanks have been used for engines up to 50-horse power.

Cooling towers are used also on small stationary engines. The water falls in a thin sheet or spray from the top of a small tower over screens and is thus exposed to the air and becomes cooled by the evaporation of a portion of the water. There will, of course, be a loss of water commensurate with that lost in the hopper cooled system. It is, in fact, the evaporation of the water that disposes of the heat and causes the cooling. In this system, as in the radiator system just described, a circulating pump is essential.

In the case of air cooled engines the cylinder temperature must be kept low enough to prevent the burning of the lubricating oil, consequently it cannot be allowed to become much hotter than either the water cooled or the oil cooled engines. This means that there must be a large radiating surface and some provision must be made, except in the smallest engines, for some sort of air circulation. This is accomplished by means of fans operated by the engine itself or by a combination of a fan and the rapid motion of the engine as in the case of an automobile. It is customary and necessary to make the cylinder walls as thin as possible consistent with strength and then rib them with ribs of thin metal which expose the largest possible amount of radiating surface. So far as the writer can learn there is no rule for determining the amount of radiating surface per horse power. Different designers use different values. It seems to be generally conceded that single cylinder engines of greater than 10-horse power should not be built air cooled.

The depth of the jacket space for water or oil may be varied considerably, depending upon conditions. If made shallow, the velocity of the cooling medium must be much greater than if made deep. The medium, be it water or oil, must take up a certain amount of heat. This amounts approximately to 4,000 heat units per horse power hour and sufficient of the medium must be brought in contact with the cylinder walls during the interval to accomplish the desired result. This means that about forty pounds of water must pass through the jacket every hour for each horse power developed. If oil is used and the temperature of the cylinder is maintained the same, about fifty pounds of oil must pass through because the specific heat of oil is only eight-tenths that of water.

In considering this problem of cooling it seems evident that some economy would be obtained by using a thermostatic control to maintain the jacket temperature constant. Without such a device, the maximum temperature is reached only if the engine is on full load. Under light load the temperature of the jacket water becomes much less because with a pump running at a uniform speed the same quantity of water will flow through the jacket constantly and when the engine is running light and burning a small quantity of fuel it will not be heated as high as under full load. The result is that the en- ne is less efficient on light load, due partly to the excessive loss of u to the jacket water. It is an easy task to arrange a thermostatic control to maintain a constant jacket temperature and thus regulate the loss of heat to the jacket under all load conditions. It would seem as though there might be enough saving effected by such regulation in engines of any considerable size to make such a regulating device quite profitable.

In engines which burn kerosene or some of the heavier oils, it is necessary to inject water directly into the cylinder to keep the temperature down where pre-ignition will not occur. The water absorbs a part of the heat set free at ignition when it is turned into steam.

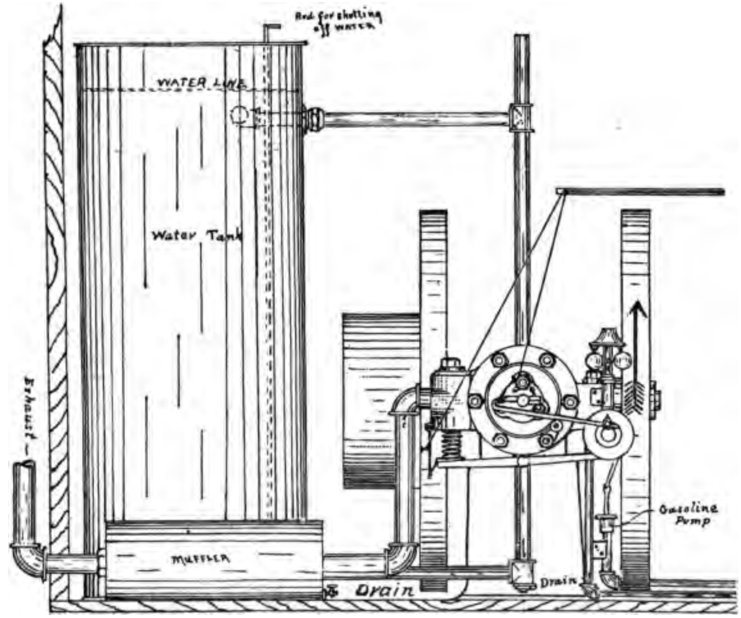


FIGURE 1. THE GRAVITY OR THERMO-SYPHON SYSTEM OF WATER CIRCULATION FOR COOLING THE CYLINDER.

In fact, on account of its latent heat of vaporization, a given volume of steam will contain between five and six times as much heat as an equal weight of air or other gas at the same temperature. A part of this heat may be turned into work on the expansion stroke but if so only a very small part because the steam is highly superheated even when the exhaust valve opens. Superheated steam acts almost the same as the other products of combustion in the cylinder and expands at practically the same rate. The effect of the water appears to be to prevent an excessive pressure at the beginning of the stroke, to hold the temperature of the cylinder within bounds and by so doing prevent pre-ignition. In addition to this it causes the engine to run smoother and quieter and, in general, with greater efficiency. It is usual to use about as much of water by weight as of fuel. This water is used, not so much with the hope of increasing the economy of the engine as to keep the cylinder temperature down within working limits. It is then, primarily, one of the cylinder cooling devices.

Some writers claim that it is impossible to cool a piston of greater than sixteen inches in diameter with the ordinary means of a cylinder jacket. The center of the piston—being so far from the cold surfaces—does not radiate its heat fast enough and becomes red hot, thus causing pre-ignition. It is a question if pistons can safely be made up to sixteen inches without water cooling. Certainly this is about the limit of size.

LESSON V.

The results of the farm motor trials in Winnipeg show that the figures given in the last lesson for the cooling water required in a hopper cooled engine hold good also for engines in which the water is pumped over a screen and allowed to drip into a tank or receptacle below. In the trials above mentioned, the water consumption was practically four-tenths of a gallon per horse power per hour. The tractors provided with closed radiators of the automobile type apparently used no water at all. This statement is not strictly accurate, because there is always some loss through the vent in the top of the radiator in the form of steam, but it is very small and amounts to very little even in quite large engines. Where a radiator is used the heat is carried away by radiation through the metal walls of the radiator and not in the form of latent heat by the formation of steam.

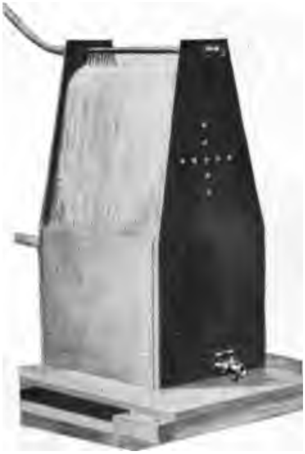


FIG. 2. THE COOLING TOWER PRINCIPLE. A QUICK WAY TO COOL THE WATER.

The same is true in the case of oil cooled engines. The radiator iates the heat and practically no oil is lost. Of course some of ne more volatile portions of the oil will escape, but in oil that is prepared for the purpose the volatile parts have been practically all driven off beforehand and there is almost no possibility of loss.

The amount of radiating surface required for a certain size or power of engine is very hard to calculate because there are several factors that have an influence which must be first determined for the particular engine under discussion. These are: the kind of metal which is used in the radiator, its thickness and distribution, the velocity at which the cooling medium is circulated, and whether or not a blast of air passes over the cooling surfaces. With all of these variable factors it is difficult to determine, without experimenting, just how many square feet of surface are required. A radiator with thin walls will radiate more rapidly than one whose walls are thicker; and then the connecting of the metal has much to do with the efficiency of the radiator. Copper or brass is about the best material to use but it is expensive and cannot be used except on high grade machines where cost is not considered. A blast of air over any radiator helps materially. The heating of every pound of air one degree Fahrenheit requires one-quarter of a heat unit, and the greater the difference between temperature of the jacket and that of the temperature of the jacket and that of give up its heat. Consequently, if a large mass of air is passed over the radiator the temperature of the air will not be raised very much but the flow of heat will be rapid owing to the wide difference in temperature between it and the radiator walls. In some farm engines, like the Hart-Parr, for example, a blast of air is caused to flow over the radiator pipes by the exhaust of the engine. The radiator is enclosed in a stack in which the exhaust enters near the top. As it passes out, a partial vacuum is formed which causes cool air to rush up from below and over the tubes. The accompanying cut will make the explanation perfectly clear.

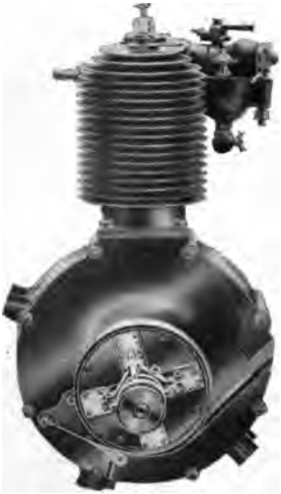


FIG. 3. AN AIR COOLED ENGINE WITH TRANSVERSE RIBS AROUND CYLINDER.

In small sized engines, using kerosene, some cooling is obtained by introducing a certain amount of water with the fuel. When the engine is working under full load it is sometimes necessary to use fully as large a volume of water as of fuel. This, as has been pointed out before, does not add to the efficiency of the engine directly but does help indirectly by keeping the temperature of the cylinder from getting so high as to cause pre-ignition, and it also, for the same reason, makes the engine run much smoother and better.

Another thing that is of importance is to use as pure water for the cooling medium as can be obtained. Rain water is the best for this purpose, since it does not contain any mineral salts that will be precipitated and form a hard scale on the inside of the jacket walls or radiator pipes. In some parts of the country ordinary well water contains large quantities of mineral impurities which give considerable trouble after the engine has been run long enough for a thick scale to be formed. It must be remembered that the mineral portions in any water are not evaporated but remain behind in the vessel after the steam has escaped, also, that when water is heated almost to the boiling point certain of the mineral salts are precipitated in the form of scale. Consequently a hopper cooled engine, or one fitted with a cooling screen, will become covered with scale in the course of a short time if the water is bad. An engine fitted with a closed radiator that uses the same water over and over will give much less trouble from this source and is the preferable engine to use, other things being equal.

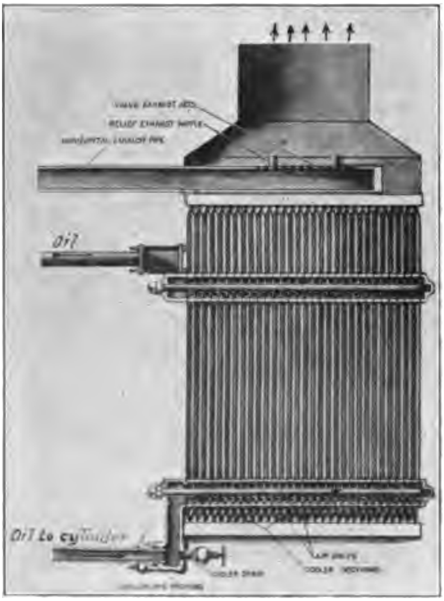


FIG. 4. HART-PARR METHOD OF OIL COOLING THE CYLINDERS.

In the last lesson we remarked that a piston sixteen inches in diameter was perhaps the largest size that could be cooled through the cylinder walls. This may perhaps be true for rather slow running engines that use a low grade gas for fuel, but heavily loaded engines, using gasoline or kerosene, should not be made larger than with a ten-inch bore of cylinder; anything larger is liable to give trouble in cooling. It is true that some twelve-inch cylinders are on the market but the writer is of the opinion that if such engines are designed with the right compression to give good economy and are run for a considerable length of time on full load there will be great difficulty in keeping the cylinder properly cooled. In large sized engines of from twenty to fifty inch cylinder bore it is customary to introduce water into the interior of the piston, usually through a hollow connecting rod.

CHAPTER III.

ARRANGEMENT OF CYLINDERS.

LESSON VI.

Automobile engines are usually built with square cylinders, that is, cylinders with the same length of stroke as the diameter of the piston. This has had the effect of making an engine with a high rotative speed and tolerably high piston speed. Now the power of an engine is dependent largely upon the piston speed and not upon the rotative speed, consequently it would be possible to obtain the same power with an engine with a smaller diameter and longer stroke. Thermodynamically, it appears that a more efficient engine can be built with square cylinders than with one in which the stroke is much longer than the diameter. The reason for this idea is that there will be less loss of heat to the cooling water if the speed is high than if it is low, for it is a well known fact that the heat lost is dependent very largely upon the time the hot gases are in contact with the cylinder walls.

Practical considerations, however, lead to directly opposite conclusions. There are a number of factors entering into the discussion. In the first place, the quality of the mixture is more apt to be correct and the fuel gases more thoroughly mixed with the air if the stroke is considerably longer than the bore of the cylinder. Then the volumetric efficiency of the cylinder is higher. Where the rotative speed is high the gases are drawn in at somewhat below atmospheric pressure and then compressed.

If the stroke is long the gases will be, as before, drawn at less than atmospheric pressure, but this pressure will be higher than it is in the short stroke cylinder. The long stroke cylinder also improves the shape of the combustion chamber, making more room for the proper placing of the valves and this is no minor consideration. It is well known that the length of the combustion chamber is a function of the piston travel; consequently, if we make the piston travel longer ve must make the length of the combustion chamber correspondingly nger. Usually, for stationary gasoline engines, the length of the nbustion chamber is made equal to about one-fourth of the piston vel when the combustion chamber is a continuation of the cylinder ore and of practically the same size. For other fuels the length of ompression space must be made to correspond to the amount of compression the fuel will advantageously bear. This, however, is a factor that differs widely with the difference in fuels.

For equal engine capacity the longer the stroke, the smaller can be the diameter, for after all, the power is largely, if not entirely, dependent upon the weight of fuel burned in a given length of time. If the cylinder is long and of small diameter just as much fuel can be used as though the diameter were larger and the stroke shorter. Again, the increase in length of the combustion chamber is said to improve both ignition and combustion, both of which are important factors in engine economy, and if not absolutely reliable may cause serious loss in efficiency.

There is still another good argument for long stroke engines and that is in the distribution of the metal in the engine. It is well known that the strength of an engine depends upon the maximum pressure in the cylinder, while the capacity depends upon the mean pressure. It is also a fact that the metal is better utilized the nearer the maximum and mean pressures are together. This can be best accomplished by making the stroke long as compared with the diameter. The maximum pressure on the piston with a small piston is less than with a long one, both having the same explosive pressure. The pressure per square inch is the same in both cases, but the number of square inches is less in one case than in the other. The maximum turning effort on the crank pin can easily be shown to be less also and consequently the size of the crank pin may be made smaller. The smaller diameter of the piston makes a cylinder that is safer to withstand internal pressure.

There is a point beyond which it is not wise to go in making long cylinders, but just what this is we are not just prepared to say. Certain it is that we can make cylinders much longer than they are being made in most engines. Motor trucks now being built in France have cylinders as much as one and eight-tenths as long as the diameter of the stroke. Some engines, even, are built in which the cylinder is twice as long as its diameter and these seem to give good results.

The original free cylinder engine of Otto was built so that all the expansive force of the gases was utilized to drive the pistons. In these engines the cylinder was made heavy and the cylinder long enough to prevent the piston from being blown out. These cylinders were vertical as was necessary with the peculiar principle involved. While expansion was undoubtedly carried farther than it is advisable in the best construction, the fact remains that these engines, crude as they were, showed as good economy as many of the small engines of the present day.

In ordinary engines, expansion is carried to a point where the exhaust opens with a pressure of from thirty to fifty pounds to the square inch. There is thus a considerable amount of heat left in the gases and the power to do a considerable amount of work. This is, of course, wasted to the atmosphere when the exhaust opens. If this could be reduced by further expansion it would appear that there would be some gain in economy. Of course, by so doing, the gases would be kept longer in contact with the cold cylinder walls and there would be a corresponding loss of heat with a corresponding loss in efficiency. Then, again, if the expansion is carried too far, or where the friction of the engine is greater than the driving force, there is a loss. Nevertheless, there seems to be a point midway between the extremes pointed out which will give better results than are at present obtained with the short stroke engine and where the increase of stroke will not prove a source of loss.

These considerations appear to be particularly applicable to the four cycle engine and the writer expects to see American designers follow the lead of foreign designers in lengthening the stroke and reducing the bore of gasoline engine cylinders.

LESSON VII.

It was pointed out in the last lesson that a more efficient engine results if the stroke is made quite long relatively to the bore. There are a number of advantages arising from this feature in design, and foreign designers have realized the advantages for several years. This year (1910) quite a number of American builders have adopted a greater ratio of stroke to bore and the result is, of course, greater economy in operation and a machine of longer life. The inertia stresses and vibrational stresses are much greater with a high speed machine than with one that runs at a low rate of speed rotatively. In fact, the inertia is almost directly proportional to the rotative speed and the stresses set up are of considerable moment. This is another argument in favor of a long stroke engine.

It is, of course, always dangerous to generalize and this case of long stroke versus short stroke is no exception to the rule. There are certain conditions where a short stroke engine is preferable to the long stroke. This condition arises whenever the character of the work to be done requires a motor of light weight. A long stroke enne requires a long engine base, a long connecting rod, a long cylinr and consequently a heavier engine. For aeronautic work and for ight flexible automobiles where fuel efficiency is of less importance than weight or flexibility, the short stroke engine, running at a high rotative speed, will give better results. For commercial vehicles, stationary engines or farm tractors, the long stroke engine has the advantage of greater efficiency and greater durability and hence is the type to be preferred. We should say that a ratio of bore to stroke of from one and a half to two would be about right for engines used for farm tractor work. The weight of such machines will, of course, be somewhat greater, but here is a case where even a considerable difference in weight is of no particular disadvantage when measured against economy of operation and durability. In automobile work, on the other hand, there are many points to be taken into consideration besides the two just mentioned and it is necessary to design the motor to meet these conditions. It is current practice, and doubtless good practice, to make the cylinders almost square. The same is undeniably true for engines used in aeronautic work, but for the greater number of stationary engines and engines used in farm tractors different conditions apply and the long stroke motor appears to the writer to be the one best adapted to the work.

The number and the arrangement of cylinders is another matter that will bear a little discussion. It is generally conceded that a single cylinder engine is more economical than a multiple cylinder engine and the reason is easy to find. In the first place, there is less loss through friction of the moving parts, because, for the amount of power developed, there is less friction area in the cylinder and in the crank bearings. Then there is less cooling area in the cylinder for the given amount of heat generated and consequently more heat available to do useful work. In the case of gasoline engines there is, of course, a limit to the amount of power that may be obtained with a single cylinder engine, as we can easily show. The limiting size for successful heavy work is in the neighborhood of an engine with ten-inch bore and fifteen-inch stroke. This should not run at more than three hundred fifty revolutions per minute, at which speed the piston speed will be eight hundred seventy-five feet per minute. This is close to the maximum piston speed for heavy gasoline engines and as fast as it is safe to go. An engine of this size will develop, according to formula, a maximum of 35-horse power. If a more powerful engine is wanted, two or more cylinders will be required. This, then, is one reason for a multiple cylinder engine. Another reason arises from the necessity to obtain close regulation. To accomplish this it is necessary to use a much heavier fly wheel with a single cylinder engine than if there are two or more cylinders; the closer the regulation the heavier must be the fly wheel. To obtain anything like close regulation it is necessary to use a fly wheel weighing about four thousand pounds with an engine such as we have just considered. This is dead metal and places just that much additional weight and strain on the bearings. With a two-cylinder engine, the fly wheel weight may be cut down a large amount and still realize the same closeness of regulation. This will be done, of course, at a slight decrease in efficiency, but the engine will possess the advantage of more power with less weight per horse power. If we want an engine of still greater flexibility and lighter weight it may be obtained by using more cylinders. Some of the automobile engines and some of the aeronautic engines have as high as six cylinders and show the least weight for the power developed.

The arrangement of the cylinders is another matter that is discussed a good deal, and each style of arrangement can be defended almost equally well. It will be interesting, however, to take this matter up and see what each claimant has to offer. First comes the question of horizontal versus vertical cylinders. For small engines up to 200- and 300-horse power, it is generally conceded that the vertical engine is more economical because the work of lifting the piston is returned on the power stroke. While all of this work is not so returned, it is clear that a large proportion is returned. Then it is also evident that the side pressure on the cylinder is less and it is easier to make a gas tight joint between the cylinder walls and the piston. Against these advantages there is urged the difficulty of getting the piston out and of getting at the crank, both of which have more or less validity. Nevertheless, some of the largest steam engines, those used in marine service, are almost without exception of the vertical cylinder type.

LESSON VIII.

The advantage possessed by vertical cylinder engines lies largely in the fact that the weight of the piston does not bear upon one side of the cylinder as it does in the horizontal engine construction. This makes it possible to make a tight joint between the piston and cylinder since the rings bear practically with equal force upon all sides of the cylinder. An objection to the vertical cylinder engine that is sometimes urged is that there is more difficulty in oiling than in the case of the horizontal engine. Where the oil is admitted at one side of the cylinder only, this is certainly an objection since it does not have the aid of gravity to carry it over to the opposite side of the cylinder. Where the splash system of lubrication is carried out, this objection does not obtain nor does it obtain to such an extent when lubrication is effected through adding lubricating oil to the gasoline. In the case of small engines, such as are used in automobiles, the vertical style of construction is followed exclusively on the high speed cars and no trouble is experienced through faulty lubrication. In the case of very large engines the horizontal style seems to give better satisfaction.

The very large engines are usually made in one of two styles, either the cylinders are placed tandem or side by side and it is rarely that more than two cylinders are used. The tandem engines built by the Allis Chalmers Company for the United States Steel Corporation are double acting, that is, a charge is admitted first on one side of the piston and then on the other. This is an approved form of design for large units. The maximum power obtained from each engine is about 1,500-horse power. When twin engines are used it is customary to place the fly wheel in the middle between the cylinders. It is only the small, light machines that use the multiple cylinder idea. The reason for using the multiple cylinder engine is to obtain maximum power with the smallest possible weight. An engine with six or eight cylinders requires a very light fly wheel, whereas an engine of the same power with only one cylinder requires a fly wheel which weighs nearly, if not fully as much, as the engine itself. Where the reduction of weight to small amount is extremely desirable the multiple cylinder engine will always be in the lead. Where weight is more of a factor, one and two-cylinder engines will have the preference on account of greater simplicity, higher efficiency and lower repair bills.

The use of two cylinder opposed engines offers certain advantages in the matter of horizontal balance and makes a very steady running engine. The only trouble in the matter of balance is in a slight tendency for the entire engine to turn about a vertical axis midway between the cranks. This tendency is not very pronounced and for such purposes as gas tractors or locomotives it gives no trouble whatever. About the only serious objection to this type of construction is found in the length of the machine. Another feature that demands very careful attention on the part of the designer is the proper proportioning of the intake pipe if only one carburetor is used. It must necessarily be quite long and if made of large diameter the velocity of the air will be slow which will result in condensation of the gasoline on the walls of the manifold. If made small, on the other hand, the velocity will be high but this is apt to result in a loss of volumetic efficiency in the cylinder. Owing to these difficulties some designers prefer the twin cylinder engine. It takes up less space, the intake pipes are short but it does not balance quite as nicely. Both types, however, are in very common use and both have proven popular and efficient.

Offset cylinders are used on a number of machines, that is, cylinders whose center line does not cut the center line on the main shaft but passes to one side. In the case of horizontal engines the center line is made to pass an inch or more above the center of the shaft. The effect of this arrangement is to distribute the torque on the crank shaft to a little better advantage than if the cylinder were not offset. With this arrangement, when the maximum force of the explosion occurs, the crank angle will be increasing very rapidly and the turning effort in the first part of the power stroke will be largely augmented and in general be better distributed throughout the power stroke. There is no gain in power or efficiency in this arrangement, but there is a gain in the torque of an engine that becomes a decided advantage where it is subjected to a heavy, continuous load.

The V arrangement of cylinders has been exploited and has found favor with some designers of small engines but never in large units. The advantage of having cylinders arranged in V form is found in the somewhat better balancing of parts and better torque on the crank shaft. This style of construction is applicable only to multiple cylinder construction and at the present time is found only in one style of aeronautic engine built in France and in a certain type of motorcycle.

Then there is another arrangement of the cylinders in which five or seven are arranged about a central point and all act on the same crank shaft. The Gnome engine built in France and the Adams-Farwell built in this country are illustrations of this construction. The latter has been applied to automobiles and both to aeroplanes. The advantage claimed for this arrangement is that it gives perfect balance and dispenses with the need of a fly wheel. Engines of this kind are consequently of very light weight, in some cases running only a little over two pounds per horse power.

In summing up this matter of arrangement of cylinders, we see that light weight, high speed engines are always of the multi-cylinder type with the cylinders vertical or arranged in either of the two ways just described. For heavy engines the two-cylinder construction is adhered to, with the cylinders tandem or else placed side by side. Some medium sized engines have the cylinders arranged in pairs opposite each other. Vertical cylinder engines are used in nearly all small engines but the very large ones are horizontal. In fact, the vertical style of arrangement does not lend itself to engines more than 500- or 600-horse power with any advantage.

CHAPTER IV.

TWO CYCLE ENGINES.

LESSON IX.

The first successful gas engine was of the four-cycle type and that type has held the leading place in the gas engine field ever since. Owing to the fact that the original patents covered the basic principles of this type of engine, the Otto Company and its lessees held control of the business for about twenty years. In the effort of the inventors to circumvent these patents the two-cycle engine was brought out shortly after the four-cycle engine made its first appearance. It was worked upon and experimented with for a number of years but in earlier years was never as satisfactory as its predecessor in the field. At the expiration of the Otto patents most of those interested in gas engines turned their attention to the development of the four-cycle engine with very gratifying results. The two-cycle engine was laid aside for a time and it is only within the past few years that it has again come into prominence.

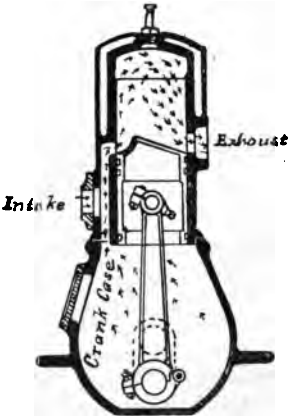


FIG. 5. A TWO PORT TWO CYCLE ENGINE.

At first thought it appears to have possibilities that are not possessed by the four-cycle engine. It takes twice as many explosions or rather has twice as many power strokes as a four-cycle engine running at the same speed. Every second stroke of a two-cycle engine is a power stroke. Consequently for a given size of cylinder it ought to develop twice as much power. This fact coupled with the fact that the turning effort on the crank shaft is more nearly uniform since the impulse on the engine occurs twice as often, makes an engine of lighter weight per horse power than its four-cycle competitor. It does not require such a large cylinder nor such a heavy fly wheel. Consequently the engine frame does not need to be so heavy and the whole engine is lighter. The fewness of parts and general simplicity makes an engine that is easy to build and which can be built very cheaply. Thus it appeals very strongly to manufacturers and should prove popular. It will be convenient in studying two-cycle engines to classify them as follows:

First.—Two-cycle, two-port single acting.
Second.—Two-cycle, three-port single acting.
Third.—Two-cycle double acting.

Each one of these different types of engines may be of the single or multi-cylinder type with any arrangement of cylinders such as horizontal, vertical, etc.

Figure 5 is a sectional view of an engine of the first class. There are no moving parts except the piston, connecting rod and crank shaft. There are no valves, cams or link work and the engine is exceedingly simple. The illustration shows the piston at the end of its travel downward after completing its power stroke. The exhaust port is uncovered and the burnt gases are escaping at the right while on the opposite side a new charge is entering from the crank case through another port uncovered by the piston. The exhaust port is uncovered first as the piston moves down and the gases pass out into the atmosphere through a number of openings which extend almost half way around the cylinder. As the piston moves down farther it uncovers the inlet or by-pass port from the crank case which admits a new charge from the crank case into the cylinder. For an instant both the inlet port and exhaust port are open and there would be danger that some of the new charge might blow out. This is guarded against by a deflector on the piston that causes the new charge to be projected to the top of the cylinder, thus displacing the burnt gases and exercising a scavenging effect. On the up stroke of the piston the intake port is first closed, then the exhaust port, and the charge that has been transferred from the crank case is compressed and ignited just before the piston reaches the end of its upward stroke. While this is taking place a partial vacuum is formed in the crank case by the pumping action of the piston and a new charge is drawn in through the carburetor and the ntake port. When the piston starts downward under the impulse of the burning charge above, this charge in the crank case is compressed

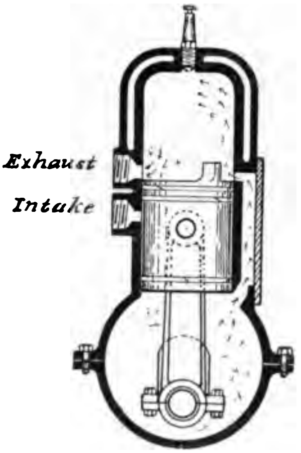


FIG. 6. A THREE PORT TWO CYCLE ENGINE.

to a pressure of five or six pounds above that of the atmosphere. When the exhaust port opens, the pressure above the piston quickly drives out the burnt gases, and then, when the by-pass port is uncovered, the pressure in the crank case is sufficient to transfer the charge quickly to the upper side of the piston. There is an instant when the gas is being transferred where the combustion space and the crank case are open to each other. This sometimes causes trouble by backfiring if there is some fire left in the cylinder from the previous charge, and the degree of compression in the crank case is slight enough so that the velocity of the flame cap is greater than that of the flow of gas to the upper side of the piston. An over-rich mixture or one that is lean, either of which is slow burning, is liable to cause this trouble. Consequently, care must be taken to have the carburetor adjusted properly and to have the piston make a close fit and not allow either a dilution of the gases by the blowing of burnt gases into the crank case or a loss of compression to the crank case on the up stroke. While explosions in the crank case sometimes occur they are not considered dangerous since the pressures developed do no damage further than to stop the engine.

A check valve must be fitted between the carburetor and the intake pipe to prevent loss of charge from the crank case during compression.

Figure 6 represents the arrangement of the three-port two-cycle type of engine. In the two-port type a check valve is required in the inlet pipe between the engine and the carburetor to prevent the charge that was drawn into the base of the engine from passing out through the carburetor. In the three-port engine no check valves are necessary, hence we have a simpler engine.

LESSON X.

Another form of construction that is gaining ground provides for placing the inlet valve in the top of the cylinder instead of near the bottom of the cylinder, as in present practice. All that is necessary in order to make the change is to carry the intake pipe a little higher and provide for a mechanically operated inlet valve. This would, of course, require a cam and a push rod, thus adding somewhat to the complexity of the engine. It appears to have the advantage of forcing more of the spent gases out of the cylinder than is possible in the older style of construction. If the gases are admitted at the top of the cylinder and they do not diffuse, but spread out laterally and force the spent gases ahead of them, there is no reason why the scavenging action should not be well nigh perfect. We are assuming, however, some things that have not been as yet thoroughly demonstrated. We do not know for sure that the gases will remain stratified and that they will not mix almost as soon as they enter the cylinder. One thing seems sure and that is that conditions can not be any worse than under the old system and there is a fair chance that they will be considerably better.

There is still another kind of two cycle engine that has been experimented with to some extent and which holds promise of satisfactory development. This engine consists of a tandem cylinder machine having the power cylinder on top and an air compressor cylinder immediately beneath and separated therefrom by a cylinder head. The air compressor cylinder is considerably larger in diameter than the power cylinder, but is necessarily of the same length since both pistons are attached to the same piston rod. During the power stroke of the engine, a charge of air is drawn into the air cylinder and from there discharged into a tank which is maintained at a certain predetermined pressure by means of a pressure regulating valve. At the instant the exhaust valve opens, air under pressure is admitted from the air tank and drives the spent charge out, at the same time it carries a charge of fuel, both entering the power cylinder from the top. The air which has been compressed has been cooled and since it enters the cylinder at a low temperature, very little greater than the surrounding air, the new charge may be compressed considerably higher than if taken in under ordinary atmospheric pressure without undue rise of temperature. In consequence, an engine built on this principle will develop considerably more power than one built on the ordinary lines and having the same cylinder dimensions. The writer saw a test made of such an engine with two cylinders each four and one-half by four and one-half running at about a thousand revolutions per minute that developed 42 electrical horse power. The exact speed was not taken, but it could not have exceeded the figure named since the exhaust impulses were easily counted.

The third type of two cycle engine alluded to in the previous lesson is nicely exemplified in the well known Koerting engine, built in this country by the De La Vergne Machine Company of Buffalo, New York. This engine is of the double acting type, that is, a charge is admitted first on one side of the piston and then on the other just as steam is used in steam engines. Figure 7 represents a plan sectional view of one of these engines, showing the general arrangment of cylnder, piston and pumps. It will be observed that the length of the ston is a little less than the length of the stroke, thus permitting he piston to uncover the exhaust ports at the middle of the cylinder at the end of each stroke in either direction. These ports are clearly shown in the illustration at the end of the piston and extending around the cylinder. The inlet valves are not shown in the cut, but are of the poppet type and are operated mechanically; their time of opening does not vary nor is there any variation in the extent of the opening. A and B are pumps which introduce the fresh charges of air and gas into the cylinder. First, a scavenging charge of air is introduced which drives out the burnt gases from the preceding stroke. At the proper time the governor admits gas into the current of air which is flowing into the cylinder. This gas has been compressed by the action of one of the small pistons. In the illustration shown, A is the gas compressor and B the air compressor cylinder. Governing is accomplished by changing the quality of the mixture.

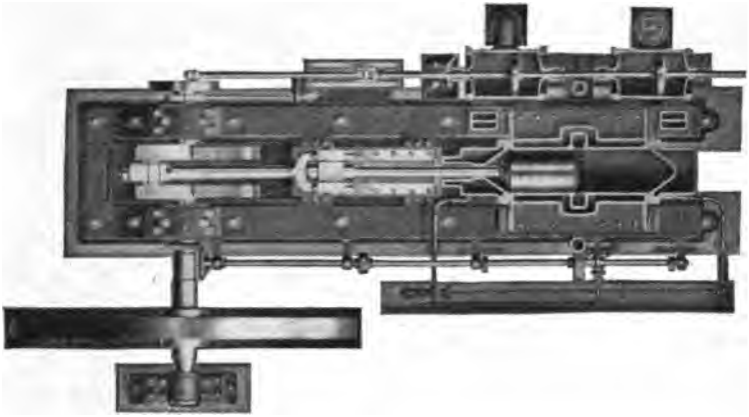


FIG. 7. SECTIONAL PLAN OF A TWO CYCLE DOUBLE ACTING GAS ENGINE.

These engines are built in comparatively large units and are adapted only to the use of gas. Under favorable conditions they work very satisfactorily and economically. They find their field for application in large manufacturing plants, such as steel works, electric lighting plants, etc.

The cut serves to show some of the details of large gas engines not generally found in small engine design. For example, the engine is fitted with a cross head and piston rod, in addition to the usual connecting rod. The base is very massive, the bearings are ample and an out-board bearing has been designed to support the shaft beyond the fly wheel. The piston is water cooled, pump oilers are used throughout and ignition is effected by means of a magneto.

Small engine builders could learn much by studying the design of large gas engines. The problems of the large engine builder have included all that the small builder had to overcome and a good many more. There were problems of cooling, of strength, of general reliability and of ignition that taxed the ingenuity of the large engine builder to the utmost. Another thing, the large engine had to prove that it was as reliable as steam in order to be considered at all, because it was designed purposely to displace the steam engine. In fact, it did not have a field awaiting its entrance as did the small gas engine; it was obliged to displace a machine that was giving very good satisfaction and prove its superiority. The fact that the gas engine has done this shows that it is very well designed indeed. As a rule we know that small engines are more or less faulty. They could generally be improved and there is no better place to go to find out what should be done than to the large engines which have displaced steam in such places as the steel works or in other large manufacturing plants.

CHAPTER V.

CARBURETION OF THE HEAVIER OILS.

LESSON XI.

It is estimated that there are somewhere around four hundred thousand automobiles in the United States at the present time (1911) and the number is increasing at the rate of at least one hundred thousand a year. If these machines average 20-horse power each, there is a total of 8,000,000 horse power represented in automobiles. No one seems to have estimated how many stationary gasoline engines there are on the farms and in the shops, but a conservative estimate would place the number at least equal to that of the automobiles. If these small machines average 5-horse power, and that seems to be a fair average, another 2,000,000 horse power must be added, making a total of 10,000,000. The near future will see the rapid multiplication of this kind of power in the form of motor trucks, farm tractors, automobiles and general farm engines. In five or ten years, the total number of engines and the aggregate horse power will be almost unbelievable.

It is this fact that is giving the manufacturer so much trouble and almost keeping him awake nights trying to find some plan whereby he can use the lower grades of oil in his engine, for it is a fact so plain that every one must realize, and does, that the gasoline supply can not meet the demands of the immediate future. In fact, it is taxed to the utmost at the present time.

Reports from the refiners show that of Pennsylvania crude oil, which supplies only fifteen per cent of the total crude of this country, only sixteen and one-half per cent is gasoline and about fifty per cent kerosene. California and Southwestern crude, which supply the other eighty-five per cent, contain only two and eight-tenths per cent of gasoline and thirty-seven and one-half per cent kerosene. It is very clear that the supply of kerosene is away and above that of gasoline and that in order to supply the amount of gasoline needed for present demands it is necessary to refine an immense amount of kerosene. The result is just what may be expected, the price of kerosene is falling and that of gasoline is rising. This condition must get worse instead of better unless kerosene comes into more general use for power purposes.

A few years ago gasoline having a gravity (Baumé) of from seventy-two to seventy-six was sold regularly for stove use. Now the Standard Oil Company announce that they can not supply better than sixty-four degree gasoline. The grade has been lowered each year and the gasoline has become much harder to vaporize. That is what makes it give so much trouble in gasoline engines. The lower the grade, of course, the nearer it approaches kerosene in quality and the more there is of it in any given amount of crude. There is no question but that the grade will go lower yet; it must in order to supply the demand. Kerosene has a gravity between forty-five and fifty and gallon for gallon is heavier than gasoline. It is also much more difficult to vaporize. As a fuel it is even better than gasoline, because it contains a greater number of heat units. If it is atomized properly it can be readily ignited and burned in a gas engine cylinder and will yield just as much or even a little more power than an equal volume of gasoline. It is much cheaper and will remain cheaper always. The whole problem, therefore, is one of carburetion, and that brings us up to the real subject of this lesson.

Carburetion is the process of vaporizing the fuel oil and mixing it with the proper proportion of atmospheric air to provide the necessary quantity of oxygen for complete combustion. Vaporization of any liquid requires heat. If water is vaporized it requires a considerable amount of heat to bring it first to the boiling point and then convert it into steam. Gasoline vaporizes very easily and the higher density it has the easier it vaporizes, that is, the smaller quantity of heat it requires. There is enough heat in air at ordinary temperatures to effect the vaporization of gasoline. Kerosene and benzine do not vaporize so easily. At ordinary room temperatures a dish of gasoline will quickly evaporate but a dish of kerosene will not. You can throw a lighted match into an open dish of kerosene at ordinary temperatures with perfect impunity, but not so with gasoline. The vapor of gasoline rises and this vapor will instantly catch fire. There is the difference between the two liquids that makes all the trouble in carburetion. The vapor of kerosene does not begin to rise until a temperature of somewhere around one hundred twenty degrees is reached. The necessary heat to vaporize gasoline is obtained in large part from the atmosphere and the rest from the heat of the cylinder itself after the engine gets to running. The heat to vaporize kerosene must come from some external source that is artificially heated, or rom the cylinder. A consideration of these facts has brought out wo styles of carburetors which will presently be explained.

Before proceeding with the explanation of these two principles, we will first give a little more consideration to the effects of heat and temperature. When gasoline vaporizes it does so at the expense of the heat in the surrounding atmosphere. The heat absorbing property of gasoline can easily be demonstrated by pouring a small portion on the palm of the hand. It vaporizes very quickly and in doing so robs the hand of heat, that is why it feels cool. It is taking away the heat from the hand. It has a refrigerating effect. When gasoline vaporizes in a carburetor it cools the air by absorbing its heat to perform internal work on itself in changing from a liquid to a gaseous state. Even on a warm day the charge of gasoline vapor that goes into the gasoline engine cylinder is uncomfortably cold. Automobile manufacturers have in some measure aided carburetion by arranging to draw heated air from across the cylinders. This materially aids carburetion, especially when the normal temperature of the air is low. The cooling effect of refrigeration is often shown in the freezing of the carburetor. The gasoline does not freeze, but the moisture that is in the air striking the cold walls of the carburetor freezes. This may happen even when the outside air is quite warm, if carburetion is rapid enough. The writer saw this demonstrated once in a room when the thermometer showed a temperature of seventy-two degrees. We were running a two cycle engine at a rate of a thousand revolutions per minute, which is the same, so far as carburetion is concerned, as running a four cycle engine at two thousand. The carburetor under these conditions became coated with frost in a very few minutes due to the rapid absorption of heat. Some

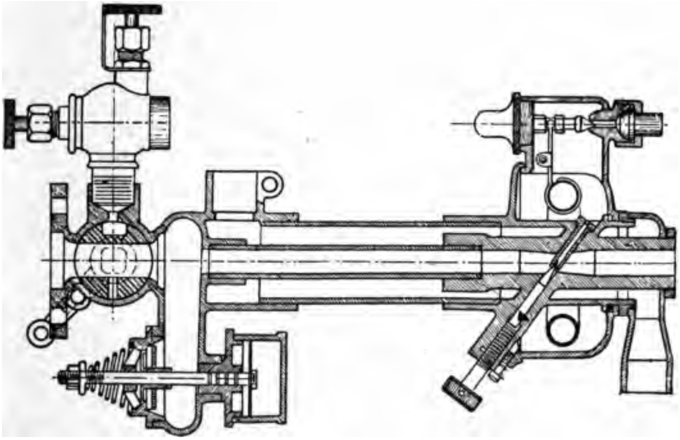


FIG. 8. A KEROSENE CARBURETOR DESIGNED FOR AUTOMOBILE USE.

one opened a window in the shop to let out some of the gas and the draft of cool air was sufficient in less than a minute to freeze the carburetor and stop the engine.

With these fundamental facts in mind it will not be difficult to understand the action of the carburetor which forms the subject of the illustration, figure 8. In this device the kerosene is heated to a temperature of around two hundred degrees in the carburetor bowl by means of the exhaust from the engine. This passes down through the center of the bowl and out at the bottom through the connection shown at the left. A certain amount of air is taken in through the central tube and passing across the fuel nozzle carries the vapor up close to the engine where it mixes with more air that passes in through the auxiliary valve shown opening into the left side of the upper chamber. The inner tube which carries the charge is made purposely small in order that it may be kept at a high temperature. A small starting carburetor to be used with gasoline is used in connection, and the inventor says usually one minute is all the time that is required before turning on the kerosene. This carburetor was designed especially for the use of automobiles, but there is no reason why the same principle could not be applied to any engine.

LESSON XII.

Two principles are made use of in the carburetor described in the last lesson. One is vaporization by means of heat from the exhaust gases and the other atomization by the usual means of delivering the oil fuel into a rapidly moving current of air by means of a spraying nozzle. The temperature in the vaporizing chamber is not sufficient to vaporize more than a small portion of the total mass of the fuel. In fact, only the lighter portions are affected by the heat at all. The greater part goes into the cylinder in the shape of a fog or minutely divided vapor. If the temperature were high enough to effect complete vaporization, it would be upwards of one thousand degrees Fahrenheit, or what would correspond to a dull red heat of iron. Gas of this high temperature would be quite certain to ignite when air is introduced to form a combustible mixture. We may assume, therefore, that since there is no tendency to ignition in the neighborhood of the auxiliary air valve that the fuel has not been very thoroughly vaporized and that the mist or fog certainly exists. The fact that a certain portion of the lighter parts have been vaporized aids both ignition and subsequent combustion and the action of the carburetor is in the main satisfactory.

Carburetors have been designed in which an attempt was made to gasify the oil completely before it enters the cylinder, or before it was allowed to be mixed with air. Up to the present time the results obtained have not been entirely satisfactory because of the fact that exceedingly high temperatures are necessary for complete gasification. When this gas is sufficiently cooled down to be mixed with the air, a large part of the vapor condenses in the form of drops and thus partially defeats the object originally desired. It is a fact that a vapor will fall in the form of drops and condense on the walls of the admission passages and even on the cylinder walls much more quickly than if the fuel is in the form of a fog or mist. Even though the vapor of kerosene were admitted as such into the cylinder of an engine it would condense on the walls because they are so much colder than its vaporizing point. Fuel thus condensing on the walls of the cylinder is difficult to burn completely because of the fact that air can reach only the outer surface of the drop and vaporization takes place slowly. The result is after burning, that is, burning during the working stroke and incomplete combustion and a rapid carbonizing of the cylinder walls and piston head.

The possibilities, therefore, in the direction of complete vaporization of the heavier oils before being introduced into the cylinder by any form of carburetor are not promising. Better success will undoubtedly be obtained through partial heating and the vaporization of only a small part of the charge while the major portion goes into the cylinder in the form of a fog.

There are quite a number of designers who maintain that external heat is not at all necessary. They depend entirely upon atomization of the fuel charge and the heat of the cylinder to vaporize enough of the lighter portions to form a readily ignitible gas. In order to start an engine of this kind recourse must be had to some of the lighter petroleum products which vaporize at atmospheric temperatures. Then after the engine is sufficiently heated, which will require only a minute or two, the heavier oil may be used and will continue to work successfully as long as the engine is working under a load heavy enough to keep the cylinder reasonably hot. These carburetors work very well when properly designed and give general satisfaction and fair economy. The mist or fog form of the charge is somewhat slower to ignite than is the vapor of a light gasoline and there is undoubtedly a certain amount of after burning in the later parts of the stroke which keeps the cylinder hotter than would be the case with gasoline. It also doubtless accounts for the fact that a kerosene engine requires a greater quantity of cooling medium than does a gasoline engine of the same capacity.

Another factor in regard to cooling must be considered and that is, volume for volume, kerosene contains almost ten per cent more heat than does gasoline. This accounts also for the claim made by some of the kerosene engine builders that their engines will develop more power than a gasoline engine of the same size. It is a fact that since both are heat engines the one that uses the richer fuel should have more power. There are, however, certain companies that misstate the amount of additional power which may reasonably be expected.

Most of the companies manufacturing large kerosene or distillate engines find it advisable to introduce a certain amount of water directly into the cylinder with the fuel charge. The effect of this water is not generally well understood. It is sometimes stated that water increases the efficiency of the engine, and the assumption is that it increases the value of the fuel. This can hardly be true when we consider the fact that water in itself has no heating value. It acts as a diluent and as a heat absorber. As is well known, water requires an immense amount of heat to change it from the watery form to steam on account of its high latent heat of vaporization. Whatever water, therefore, is introduced into the cylinder, must be changed into steam at the expense of the heat of the burning fuel, and as the temperature in the cylinder up to the time the exhaust valve opens is higher than the heat of saturated steam under the given pressure, the steam thus formed must pass out of the cylinder as such, carrying with it its heavy load of heat. The most of this heat has done no useful work. Its principal effect has been to do internal work on the water and change it into steam and that only. In other words, the water acts principally as a cooling medium for the cylinder. It is true that during expansion it does some work on the piston, but not nearly as much as would be done by the hot gases without the use of water. We may say, then, in conclusion that the water is rather a necessary evil than a theoretical necessity. In certain tests that have been made, higher efficiency has apparently been obtained with the use of water than without, but the fact nevertheless remains that its action is mechanical rather than thermodynamical and under ideal conditions its use would prove a detriment.

The foregoing must not in any sense be considered as an argument against the use of water in heavy fuel engines because the writer is convinced that its use is necessary. The argument is entirely a theoretical one and merely points out one of the many places where theory and practice diverge.

CHAPTER VI.

GAS ENGINE GOVERNORS.

LESSON XIII.

In order to understand how the governor of a gas engine works it is necessary first to understand how the pressures vary in a gas engine cylinder. This is most conveniently studied by considering an indicator diagram under varying conditions. In the first place, the function of a governor must be clearly borne in mind. Its purpose is to keep the speed of the engine as nearly constant as possible. To accomplish this result it must vary the driving force that actuates the piston in exact accordance with the resistance that the engine encounters from moment to moment. In other words, the average pressure on the piston must be adjusted to the load the engine is carrying. This may be done in a variety of ways, depending upon the style of engine and the style of governor determined upon. The most common method is to reduce the average pressure by reducing the number of power strokes. This is the hit and miss method. Another way is to allow the engine to accomplish every power stroke required of its cycle and vary their intensity in accordance with the load. This is best exemplified in the throttling style of governor. There are a number of variations in these two general methods of governing that will be explained and commented upon as we proceed.

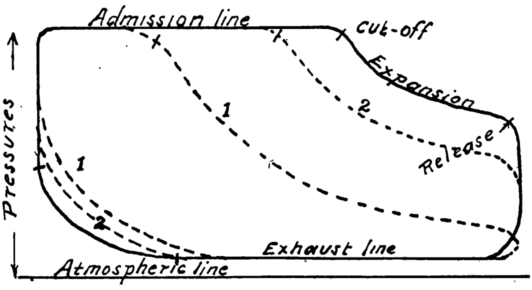


FIG. 9. IDEAL INDICATOR DIAGRAM FROM CUT OFF GOVERNED STEAM ENGINE. THE DOTTED LINES SHOW PRESSURE DURING LIGHT LOADS.

To begin with, let us consider the ordinary steam engine indicator diagram, as shown in figure 9. The length of the card represents the length of the stroke of the engine to some scale. Vertical distances represent pressures in the cylinder to another scale. The pressure in the cylinder at any point in the stroke can be seen graphically by referring to the diagram and exactly measured if the scale of the indicator spring is known. The different lines of the diagram are carefully marked in the drawing. It will be noticed that the function of the steam engine governor is just the same as that of the gas engine governor so far as regards varying the power in accordance with the load on the engine, except that the steam engine governor has an unlimited supply of steam to draw upon and allows only enough to enter the cylinder to accomplish the work the engine is required to do. It may do this by allowing steam of boiler pressure to enter and varying the point of cut-off, making it earlier as the load becomes lighter and later as the load becomes heavier. The dotted lines show how cut-off occurs under light load. Another steam engine diagram is shown in figure 10, in which cut-off always occurs at a fixed point but the initial pressure is made to vary with the intensity of the load. The dot-

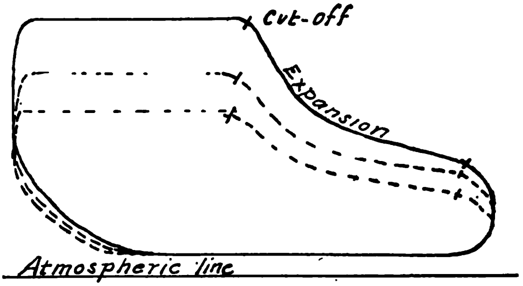


FIG. 10. DIAGRAM FROM A THROTTLE GOVERNED STEAM ENGINE. AT LIGHT LOADS THE STEAM IS THROTTLED AND PRESSURE CANNOT RISE AS HIGH. CUT OFF REMAINS THE SAME. DOTTED LINES SHOW HOW PRESSURES ARE REDUCED AT LIGHT LOADS.

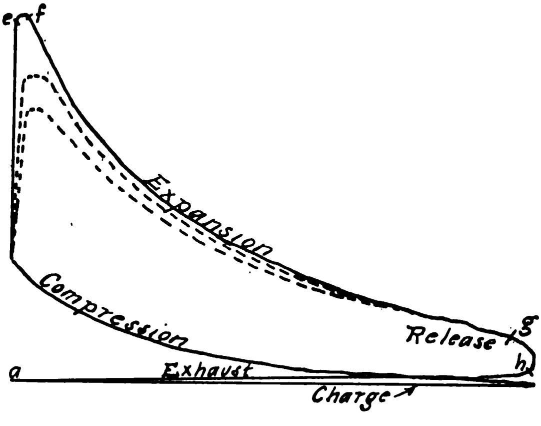


FIG. 11. IDEAL DIAGRAM FROM A FOUR CYCLE GAS ENGINE. THE DOTTED LINES SHOW EFFECT OF BURNT GASES IN PRESSURES IN CYLINDER.

ted lines again show what happens when the load becomes light. In either case it will be observed the average pressure on the piston for the whole stroke is made to vary in accordance with the load.

The same thing is made to happen in the case of the gas engine, only by different means. Figure 11 represents an ordinary gas engine diagram. The various lines are named and show what occurs in the cylinder during the time each line is drawn. The charge is first drawn in, then compressed and ignited. The straight vertical line at the left shows the rapid increase in pressure that occurs during the burning of the charge. The pressure is maintained for a short time after the piston passes dead center, as shown by the line *e-f*, on account of the burning of the charge. After the point *f* is passed the pressure falls rapidly, due to the expansion of the gases behind the rapidly moving piston. At *g* the exhaust valve opens and the pressure quickly falls to the pressure of the atmosphere. *h-a* represents the pressure line in the cylinder during the exhaust stroke. It will be noticed that the high pressure is obtained just as the piston passes center, and that at the end of the stroke it is almost nothing in comparison. There is no point of cut-off as in the steam engine and there is no way to obtain such results in the ordinary gas engine. With a given quality of gas, a fixed point of ignition, and a piston speed that does not materially vary, every pressure diagram will be exactly alike from the same engine. There are, it will be observed, a number of variable factors and we will now proceed to investigate them and see how they may be taken advantage of in order to govern the engine.

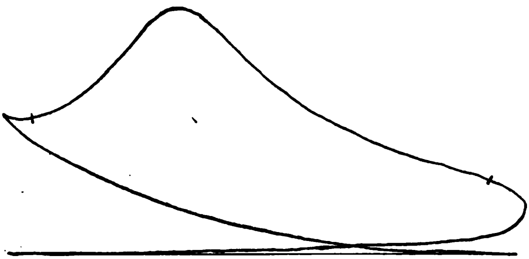


FIG. 12. DIAGRAM SHOWING LATE IGNITION. IGNITION DID NOT OCCUR UNTIL PISTON PASSED CENTER. THE HIGH EXPANSION LINE SHOWS AFTER BURNING.

The dotted lines show what happens on the next succeeding stroke after the first, or after a hit and miss governed engine has taken two or three explosions. The pressure line does not rise quite as high because of the burnt gases that remain in the cylinder from the preceding stroke. These serve to dilute the charge and make it slower burning for one thing and less powerful for another, on account of the fact that the engine takes in a somewhat smaller charge on this second charge than when it was completely scavenged. The difference, however, is not large and hardly warrants making use of this principle in order to govern the engine.

Figure 12 shows what happens when ignition is retarded. The pressure line, instead of rising abruptly at the beginning of the stroke, does not begin to rise until after the piston has started forward on its power stroke and then it rises slowly and the greatest pressure occurs at or near mid-stroke. The total average pressure is greatly reduced and the pressure at the end of the stroke is considerably augmented. The power developed on a stroke like this is considerably less than if ignition occurred at the right time, that is, a little before the piston started on its power stroke. The mixture is slow burning and it appears as though the flame cap could hardly overtake the swiftly moving piston. The result is that the gas is still burning when the exhaust valve opens and flame will burst from the exhaust pipe. This causes warped and burned exhaust valves unless extra precautions are taken to cool the valves. However, while there are some disadvantages connected with this practice, it appears possible to vary the average pressure on the piston by this means and so govern the engine. In other words, it would be possible to attach a governor to the timing lever of a gas engine and govern the speed of the engine quite effectively. It would, however, be a wasteful method of doing the work and a better plan would be to miss some of the explosions altogether as is the current practice with hit and miss governed engines.

LESSON XIV.

It was pointed out in the last lesson that while it might be possible to govern a gas engine by merely changing the time of ignition, such a method was open to serious objection. It is, in the first place, wasteful of fuel, and in the second, if too late it has a tendency to overheat the engine and if too early it will cause heavy and unnecessary stresses on the piston which will be transmitted to other parts of the engine and may cause serious trouble. Governing by too early ignition causes back pressure on the piston which has the same effect, as far as power is concerned, as reducing the driving force.

There is still another method of governing that might be adopted and that is to control the back pressure by closing the exhaust valve early in the exhaust stroke. This method is also open to objection since it retains a portion of the hot gases in the cylinder, thus causing overheating and the burning of the lubricants in the cylinder and besides it is wasteful of fuel. There remains, therefore, only one general method of speed control and that is through the supply of fuel. This may be accomplished in a variety of ways. Among small gasoline engines the simplest and most satisfactory method is the hit and miss. This method is perhaps the most economical. A charge of full power is admitted to the cylinder and ignited. The force of this impulse is then distributed over a number of strokes of the engine until its force up to a certain predetermined point is expended when another charge is admitted. If the engine is running under full load the governor will not cut out any explosions, or at most only a very few, say one in four or five. If running under light load it will take one explosion and then cut out three, four, or even five.

Under this system of governing, the compression is always constant and a maximum for the given fuel. It can be shown that the efficiency of any gas engine is dependent upon the degrees of compression of the charge and since the hit and miss system allows the highest possible compression for every power stroke, it is, everything else being correct, a very economical system to use.

It has, however, one serious objection and that relates to closeness of regulation. It is impossible to obtain absolutely steady motion from a machine driven by an intermittent force which acts only at intervals. The only way to obtain constant speed is to have a constant force properly proportioned to a machine which meets with a constant resistance. This is an ideal condition that does not obtain with any machine whatever. With large engines driving an electric generator running a certain number of lights, we approximate such conditions quite closely so far as the resistance is concerned, but even then the governor is in constant action letting in a little more steam on one stroke and cutting off a little more on another. The speed of even such an engine as that is not constant but varies between narrow limits determined upon by the designer when the engine was being planned. It must be understood that all governors, be they of steam or gasoline engines, depend upon changes in the speed of the engine to set them in motion, otherwise they could not act at all. In the case of engines that are to operate electric lighting dynamos a close regulation is necessary and designers construct the governor to act within certain narrow limits of speed, say one and a half per cent above normal and the same amount below. This gives the engine a permissible variation of about three per cent which is very close regulation indeed, and much closer than most gasoline engines are capable of. Hit and miss governed engines can not govern quite so closely as this because of the fact that when a charge is cut out the speed is liable to drop on the next stroke to a point where the governor will act, but it will do no more good since three more strokes must take place before another charge is taken into the cylinder. Then when it does get a charge the speed will suddenly above normal. The variations in speed, while not of great magi tude, are sudden and violent. The only method of overcoming tl effect is to provide heavy fly wheels whose inertia will absorb t force of the heavy impulse and give it back again on succeedi strokes.

A better method so far as closeness of regulation is concerned is vary the intensity of the impulses and have them occur at regu intervals. This may be accomplished in any one of three ways:

1. By throttling the charge.

2. By cutting off the charge at some intermediate point in t stroke.

3. By reducing the quantity of the fuel, that is, by affecting t quality of the mixture.

The first method is a very common method and the results fairly satisfactory so far as close regulation is concerned, but it open to the objection that it is not very economical for the rea that only a partial cylinderful of gas is admitted, or, what amou to the same thing, the gas is admitted at some pressure less than tl of the normal and consequently compression is reduced.

The second method results in exactly the same effect. The cha is admitted let us say at atmospheric pressure, for half or two-thi of the stroke and then cut off. No more gas is admitted; what ready has entered the cylinder expands and its pressure falls; con quently, at the end of the stroke the gas is at less than atmosphe pressure in the cylinder. When the charge is compressed its fi pressure is considerably below the point suitable for the given fı This method of governing gives excellent results aside from the defect mentioned.

The third method does not affect the quantity of the charge mitted to the cylinder but does affect its quality. At anywhere n full load it gives excellent service, but under light loads the gas n give trouble in igniting because it is so lean.

LESSON XV.

The hit and miss governed engine misses one or more explosi whenever the speed exceeds a certain predetermined value for wh he governor is adjusted, by the cutting out of a charge or the c ng out of ignition. The governors used on engines governed principle vary widely in details of construction and to some t in their application.

not the writer's purpose to attempt to describe all the differ- pes of governors but to present enough to give the reader a concise idea of the leading types of governors and the princi- volved in their operation.

and miss governors are designed to act primarily either on the t valve, the inlet valve or the igniter. The plan commonly d is to attach the or in such a manner ; will hold the ex- valve open during ie the engine should lly take in a charge. n the suction stroke piston, air will be in through the ex- port and since this s the vacuum in the r, the automatic ion valve will re- losed and a charge will be drawn in h the exhaust valve. , however, to the restricted opening exhaust valve and eed of the piston, will be a period mid-stroke when the pressure in the cylinder will be slightly d and there will be a tendency for the inlet valve to open and a small amount of gas. Any portion of a charge admitted this idle stroke would be lost and therefore it is necessary to some means of locking the admission valve during the time aust valve is held open. This is accomplished in a variety of ome of which will be explained further along in these lessons. charge of air drawn in through the exhaust valve opening and xpelled does two things, it cools the cylinder and it gets rid of f the burned gases left from the preceding stroke. In other it scavenges the cylinder and the next succeeding charge will greater volume and capable of doing more work than any of gular charges that occur while the engine is taking every ex- . This fact is clearly brought out in a series of indicator dia- taken while an engine is working hard. The pressure imme- succeeding a missed stroke is considerably higher. A graphic

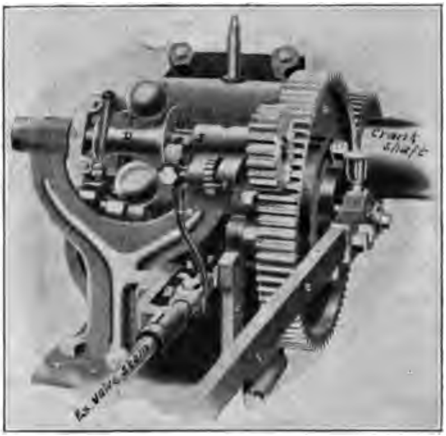


FIG. 13. HIT AND MISS GOVERNOR WHICH ACTS ON THE FUEL VALVE.

illustration of this truth was shown in figure 60 which appeared the May issue.

The objection to this method of governing, aside from a cert irregularity of action, which was discussed in the last lesson, ar from the drawing in of a charge of air through the exhaust p This has a tendency to draw bits of carbon and other foreign ma into the cyli that may ca trouble.

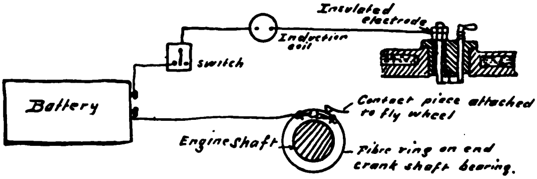

Insulated electrode
Induction coil
switch
Battery
Contact piece attached to fly wheel
Engine Shaft
Fibre ring on end crank shaft bearing.

FIG. 14.

Engines are so times equipp with a gove that acts upon fuel valve only prevents it f opening and taking in a charge when the speed passes a cer amount. The rest of the valve mechanism acts in the ordinary ner, that is, the exhaust valve contiues to act just as though governor had not interfered with the action of the fuel valve. method of governing is very closely akin to the one first descri

The method of governing by cutting off the ignition is used only a very few engines. It allows a charge of gas to enter and prevents it from firing, thus cutting out a power stroke. Of course the charge that was taken in will be compressed and again expanded, perhaps several times before it is finally ignited. If the cylinder rings are perfectly tight and no gas escapes, this method of governing works very satisfactorily, but t are almost no engines made in which there is not some loss of ga the compression stroke and consequently this particular metho open to serious objection on that account. It may be urged that w n engine begins to lose compression it ought to be overhauled ut in good condition at once, and this is true. Nevertheless, we ca scape the belief that there is a serious waste of gas in an engin

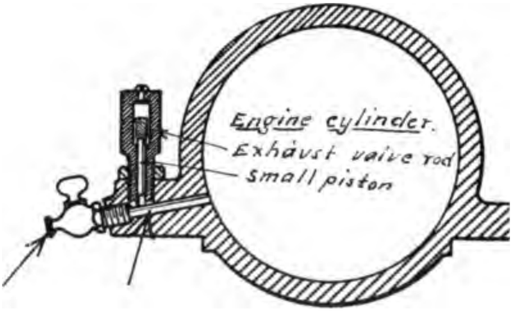


FIG. 15.

this type, especially when running light. Under heavy load the loss will be merely nominal. Another thing, this method does not make any provision for the scavenging of the cylinder.

Figure 13 illustrates a well known type of governor that operates upon the fuel valve. It is described thus in the manufacturer's book of instructions: "The governor regulates the speed by acting on the finger B through the lever A. As the speed increases, the governor balls fly out causing the spool D to push against the roller J on the upper end of the governor lever. This causes the lower end of the lever to move inward, pushing the notched finger B out of its regular position, so that the blade on the fuel lever will not strike it, thus 'cutting out.' In consequence the fuel valve remains closed and no charge is taken." In this engine there is a fuel valve and between that and the engine an inlet valve. The governor, it should be noted, acts only on the fuel valve.

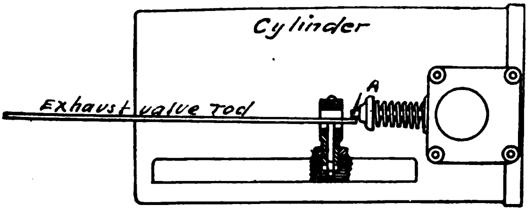


FIG. 16.

Figures 14, 15 and 16 show another type of governor in which the ignition of the charge is controlled by the governor. Figure 14 shows the method of wiring. The ground wire from the battery is attached to a metal segment which is insulated from the shaft by means of a fiber ring. A contact piece is attached to the fly wheel and makes contact every time the wheel turns around unless the centrifugal force due to high speed forces it away from contact with the metal strips imbedded in the fiber ring. A thumb nut and spring is provided to adjust the position of this contact piece, all of which is carried around by the fly wheel, to which they are fastened. This cuts out the ignition of the charge, which must remain in the cylinder until the speed drops low enough to close the circuit at the fly wheel and allows it to be completed when the igniter points are brought together by the forward movement of the piston.

The exhaust valve will remain closed because of the fact that it depends upon the force of an explosion in the cylinder to force a small auxiliary piston upward, which, in turn, lifts the exhaust valve rod until it engages with the exhaust valve stem. Figures 15 and 16 illustrate very clearly this part of the mechanism and need no further explanation.

LESSON XVI.

Inertia and centrifugal force are both employed to help actuate th mechanism of gas engine governors, thus giving rise to types of go ernors called respectively inertia and centrifugal governors. Bot are used not only on gas engines but for steam engines as well. C the two the centrifugal governor is used most and is a little mor positive and certain in action. Before going further, however, i the discussion of these governors, it may be well to define the tw terms which give them their names.

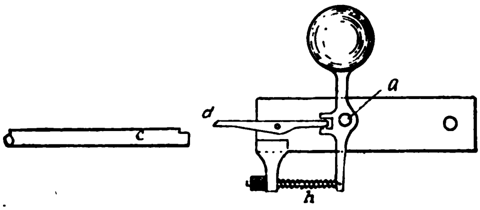


FIG. 17. DIAGRAM OF SIMPLE PENDULUM GOVERNOR.

Inertia is that property of matter by virtue of which if a body i at rest it will stay at rest or if in motion will remain in motion in straight line unless acted upon by some external force. Inertia is purely negative qua tity. It might fu ther be defined as th reluctance of a bod to change its state motion or of rest. is a property po sessed by all bodie be they large or sma heavy or light, and has to be taken count of by every designer of machinery. In many places it prove serious detriment and in others, as for example in the case of t type of governor to be shortly described, it may be turned to use account.

Centrifugal force literally means force acting toward a center. a body is in motion it will continue on a straight line unless ac upon by an external force, consequently if it moves in a circle th must be a constantly acting force toward the center, to compel it continuously change its direction. This force is called centrifu force. If a body revolves in a circle the centrifugal force requi to prevent it from flying off at a tangent will increase in accorda with the velocity of rotation—not directly—but as the square of t velocity. This principle is utilized in a great variety of ways mechanics not only for governors but in many other ways.

The inertia governor is particularly well adapted to the hit a miss style of governor. Its method of operation may be understo by considering the simple pendulum governor shown in figure 1 The heavy ball or pendulum pivoted at *a* moves back and for through the action of an eccentric on the main shaft. A compre sion spring *b* keeps it in a fixed position until a sudden change of speed changes its position, causing it to swing backward on the forward stroke thus depressing the pick blade *d* until it engages with the notch on the end of the exhaust valve rod *c*. When this occurs, the exhaust valve will be held open thus preventing the formation of a vacuum in the cylinder and the consequent entering of a fresh charge.

There are many forms which such a governor may take. Figure 18 shows how the principle was employed on a certain well known style of engine. The drawing is merely a diagram and is not drawn to scale. In this case the pendulum hangs below the sliding member *i*. An adjusting nut with spring to vary the tension is shown at *c*. A star wheel *m* moves forward and back and on every alternate forward stroke engages with the end of the exhaust valve stem *f* and opens the exhaust valve. The pawl and ratchet *d-e* cause rotation of this wheel. If the speed of the engine increases, the pendulum swings forward and the long lever *h* on the bottom lifts the block *a* and holds it up in engagement with the collar on the end of the exhaust valve stem, thus holding the exhaust valve open until the speed of the engine falls to normal. The exhaust valve when held open just touches the inlet valve on its left and at the same time holds it shut. In this case the eccentric on the main shaft must be set with its throw or highest point on the same side of the shaft as the crank.

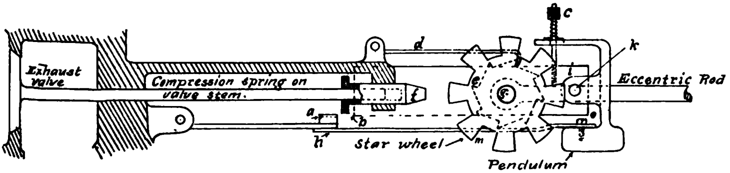


FIG. 18. DIAGRAM OF PENDULUM GOVERNOR WITH COMPLETE MECHANISM FOR FOUR CYCLE ENGINE

Figure 19 shows a well known type of centrifugal governor used on International Harvester engines. The weights *w* are attached to the fly wheel and revolve with it. They are fastened together with the spring shown in the figure and provision is made to increase or decrease the tension as desired. Increasing the tension will make the engine run faster as it requires an increase in speed to augment the centrifugal force enough to overcome the added tension of the springs. The bell crank levers pivoted at *k* are a part of the weights. They engage with the collar *c*, which is free to slide backward and forward on the shaft. This collar carries the bevelled portion *m* against which the little wheel *D* rests. When this collar slides outward under the influence on the governor weights, this little wheel i forced outward, thus depressing the pick blade *F,* which engage with a notch on the end of the exhaust valve stem, thus locking th exhaust valve open. *A* and *B* are the two-to-one gears; *A* being twic the diameter of *B* revolves only half as fast and hence opens the exhaust valve on alternate revolutions.

In this engine, as indeed in all modern engines, when the exhaus valve is locked open, the inlet valve is held shut and the electric circuit is opened s that no spark wi pass when the igniter is tripped. A of this is acco plished by simp mechanism actu ed by the govern The holding of t inlet valve lock prevents any the charge fr entering the cyli der on the sucti stroke as it mig if air did not ru in fast enoug through the e haust ports maintain atmospheric pressure in the cylinder. Indeed, some char will be sure to enter as we have found many times when the locki device failed to operate. This not only causes a waste of fuel b uncertain governing. The opening of the electric circuit is nece sary to save battery current in case a battery is used or in any eve to reduce the wear on the spark points, which is caused by the arci of the current. Every time a spark passes, a tiny speck of metal detached from one point and deposited on the other. That is wh causes roughening of the spark points and makes it necessary to fi them smooth occasionally.

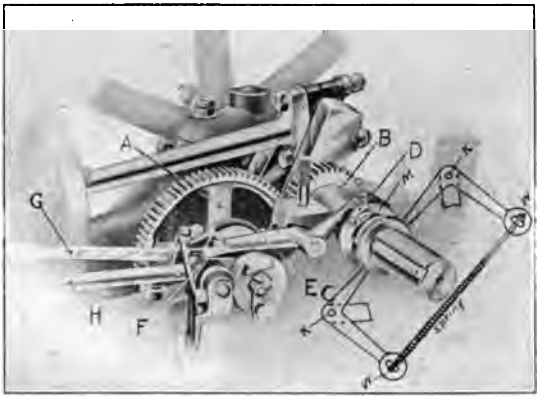


FIG. 19. CENTRIFUGAL GOVERNOR IN FLY WHEEL.

LESSON XVII.

Figure 20 shows another style of centrifugal governor which is us for make and break ignition. When speeded up the weights *w* mo outward and lift the sleeve upon which lever *l* rests. The vertic is pivoted to a pick blade at its lower end which swings upward r the influence of the governor and engages in a suitable groove e end of the exhaust valve lever and holds it open. The speed of gine equipped with this governor can be varied while the engine nning by changing the ten- of the spring *s* by means e thumb nut *t*.

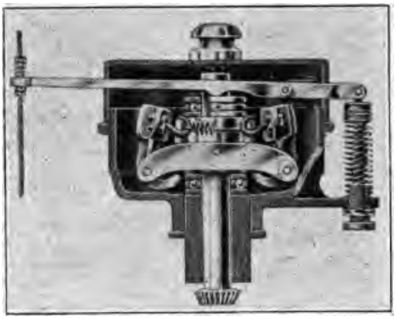
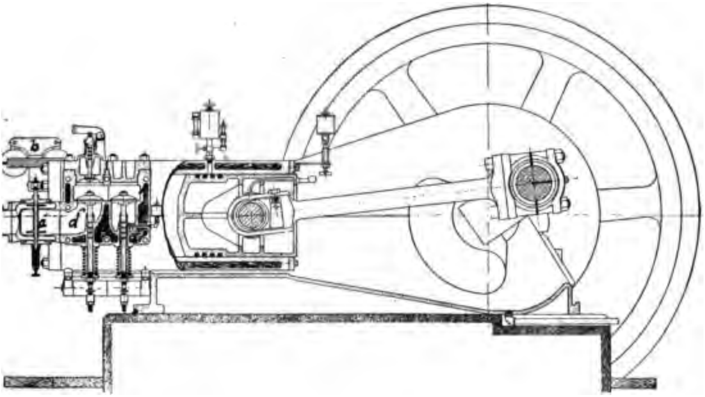


FIG. 20. SHOWING COMPACT STYLE OF CENTRIFUGAL GOVERNOR USED ON FIELD-BRUNDAGE ENGINE.

me of the earlier engines made with governors that l be changed only when the e was stopped, but the ob- advantages of being able djust the speed with the e in motion, — especially e case of small portable es, is such that most facturers are now equip- their engines with govern- hat can be adjusted while ngine is running.

rottling governors that admit varying quantities of fuel are times arranged on the plan of steam engine throttling governors. re 21 shows the arrangement of a governor of this type. The



. 21. THROTTLING GOVERNOR USED ON LARGE ENGINES BUILT BY ST. 'S MACHINE COMPANY; a IS THE THROTTLE VALVE; b, THE GOVERNOR HTS; c, THE GAS ADMISSION PIPE; AND d, THE GAS PASSAGE TO THE VALVE.

valve is of the balanced type found in all good steam engine governers and is actuated by weights which fly outward under the action of centrifugal force and move a sleeve to which the valve is affixed.

A governor of this type provides very close regulation because it does not allow a full charge to enter the cylinder. If the load is light, the opening will be so small that the gas cannot enter in sufficient volume to fill the cylinder full at atmospheric pressure. The result is that at the end of the charging stroke the pressure may be only ten pounds absolute instead of 14.7 pounds Consequently on the compression stroke the compression will be correspondingly less. This makes the engine a little less efficient as a heat engine, but unless the load fluctuates violently and is very light the major portion of the time, the lowered efficiency is not very apparent.

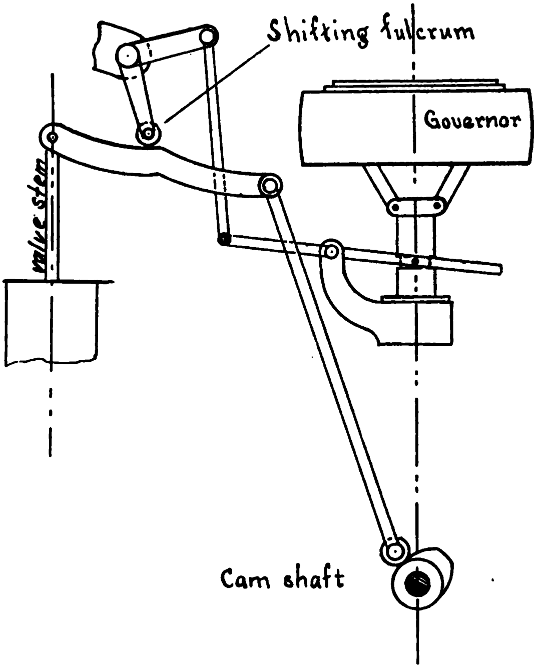


FIG. 22. THROTTLE VALVE WHICH OPERATES BY SHIFTING THE FULCRUM OF THE VALVE LEVER.

Figure 22 illustrates another governor of the same general type in which the lift of the valve is regulated by the shifting of the fulcrum about which the valve lever turns. This is accomplished by an ordinary centrifugal form of governor.

In certain oil engines such as the Diesel and Hornsby-Akroyd the governor regulates the fuel pump and regulates the amount of oil injected into the cylinder in accordance with the load on the engine. In both of these engines pure air only is taken into the cylinder during the suction stroke and then compressed. In the former, however, the compression stroke is completed before the fuel is injected, thus fuel is burned during expansion and the pressure is maintained practically constant during the time fuel is being admitted. In the latter, the fuel is injected and mixes with the air during the latter part of the compression stroke. Both engines govern quite closely, but the Diesel is by far the better of the two. In fact, it is said to govern as closely as a steam engine. It has the further advantage of constant compression, and practically constant efficiency whether running on light or heavy loads. Those governors, as previously stated, that control the quality of the mixture are uncertain under very light loads because the mixture is so very lean at those times that it may not ignite. They are of the ordinary centrifugal type and are designed to act on the fuel valve while admitting at the same time a full volume of air.

In the next two or three lessons we will take up the subject of gas engine fuels, especially petroleum fuels. We have covered the main descriptive features of the engine and from now on will consider more of the theory of the gas engine, making it, however, as simple as possible and in every case showing how the theory applies in practice.

CHAPTER VII.

PROPERTIES OF PETROLEUM FUELS AND PRI CIPLES OF COMBUSTION.

LESSON XVIII.

The sun is the source of all mechanical power on the earth. I the great central motor of the solar system of which the earth member. All heat and all energy and all power come from the It was the sun's rays in by-gone ages that created the wonderful- ests and rank vegetation of the carboniferous age. The heat of sun, falling upon fertile soil and passing through an atmospl laden with chemical atoms which were readily assimilated by the gr ing plants, caused the greatest and most prolific plant growth world has known.

As the years went by, these forests fell and the waters washed tl into low places where they were later covered with earth and rc or buried deep below the surface by earthquakes or some great c clysm of nature. Thus there were formed our coal beds which cc millions of square miles and which furnish the energy for mar the present time which he utilizes to warm his dwellings and his factories. The same energy which was stored in the coal l also stimulated animal life and there are left to us, as the herit of the long ages in which nature laid away her stores, great lake petroleum, ledges of limestone, and rocks rich in phosphates. Th according to many geologists, are what remain of the vast multiti of marine animals that filled the seas at some earlier period in world's history.

Whether this view regarding the origin of petroleum is correct, whether petroleum had its origin in a vegetable instead of an ani source, we may never know, but, whichever it was, we are assu that it is a part of the stored energy of the sun which came tc through the depths of space in pre-historic ages.

It seems as though all the past ages of the world were merel preparation for the present and that the great storehouses wl were filled during the carboniferous age were deposited against time when man should come into the fullness of his powers and t them to material account. It is only a little more than one hunc years since man learned fully the use of coal and only half that t petroleum has come into use. The results have been astound- Man has made greater material progress in the last hundred s than in any ten previous centuries of which we have history. ias utilized the energy stored in past ages, it may be somewhat lessly, but, nevertheless, he has made use of thousands of years ored energy and since energy is the basis of life and achievement is reason for the development he has made.

the past ages man has used merely the energy coming to him the sun during his own day and generation, but we of the pres- make use not only of present supplies but have drawn heavily he storehouses of the ages. We are using the stored up energy thousand ages in one and our progress ought to be a thousand s as great.

eat is the source of all mechanical energy and all the studies of nes involve a study of the laws of heat and heat energy. Our , whether they be coal or oil or a more recent vegetable product, ave a somewhat similar composition. Carbon is the basic ele- and usually there is some hydrogen. The prinicipal fuel ele- s in all cases are carbon and hydrogen. Whenever any fuel is ed for doing work it must be changed from potential into active y by undergoing the chemical process of burning. The heat set free is made to act upon some medium, either a liquid or a through which it is transformed into mechanical energy.

the steam engine the heat of the coal turns water into steam n acts upon a piston and causes it to move back and forth in a der. This motion may be translated into rotary motion by s of a connecting rod and crank and be thus made to operate inery.

e internal combustion engine differs from the steam engine in ssential particulars. In the first place, the medium used is air in the second place the fuel is burned directly in the cylinder. rtheless, it is the heat generated by the burning of the fuel that the work. That is the fact that must not be lost sight of in discussion of either steam or gas engines.

ernal combustion engines use a variety of fuel but the most y used and the most important are those derived from petroleum. egin with, then, we will consider some of the properties of the leum fuels. Petroleum, or crude oil, is found in a great many of the world. The principal fields in this country are in Penn- nia, Ohio, Illinois, Kansas, Oklahoma, Texas and California. as been located in a number of other places but the fields as yet not been developed to any great extent. Crude oil as it comes the ground is unfit for use and must be refined either wholly or in part. It is true there are some engines in which it is crude oil may be burned but even in these only the best gr crude can be used successfully.

The principal products of petroleum used for fuel in gas are gasoline, naphtha and kerosene. These are obtained by a of fractional distillation in which the oil is maintained at a temperature, or within a given narrow range of temperatur as much as will vaporizes. This vapor is conducted throug which are kept cool with running water, and condensed. The ing table shows the products distilled at the various temperat

TABLE I.

PRODUCTS	DISTILLATION TEMPERATURE	SPECI GRAVI
Rhigoline	113	0.59—
Chimogene	122—138	0.25
Gasoline	140—158	0.636–
Benzine	160—216	0.66—
Naphtha B	200—240	0.71—
Naphtha A	250—300	0.725–
Kerosene	300—500	0.76—
Lubricating Oils	500—Up	0.85—
Commercial Gasoline	125—200	0.62—

Residium, consisting of paraffine wax, asphaltum, etc., boiling poi 500; specific gravity, above 0.90 after distillation.

There are other processes of purification which need not cussed here.

Crude oil varies greatly in different parts of the country. have what is known as a parffine base and others have an base. Oils having a paraffine base yield higher percentages o line and may even be used for fuel in some engines of the type. Oils having an asphaltum base have not as yet been us successfully. These oils, after the lighter constituents hav distilled off, yield a heavy black residium resembling the asphalts and chemically almost identical with them. Th asphalts are used widely for road construction for which they have proven to be well adapted. Table II shows the per of the different grades of oil that may be extracted from the d crude oils.

The figures in Table II are only approximate, as they differ greatly in the different fields. In Table I, specific gravity must not be confused with the Baumé scale.

TABLE II.

PENNSYLVANIA CRUDE		WESTERN CRUDE	
Products	Per cent	Products	Per cent
Gasoline Benzine } Com. Gasoline Naphtha	16—18	Gasoline Benzine } Com. Gasoline Naphtha	2.5—5
Kerosene	45—52	Kerosene and distillate	35—40
Lubricants	15—18	Lubricants	30—35
Residium, wax, etc.	16—18	Residium, wax, etc.	22—26

An inspection of the first table will show that each of the different products distills within a certain narrow range of temperatures, but it is quite evident since some of the liquid distills at a lower temperature than others that the resulting liquid is not uniform in composition.

Crude oil, as a matter of fact, is a very complex substance containing a large number of related but different substances. Even gasoline is a very complex substance consisting of a mixture of several hydrocarbon compounds belonging to what chemists call the paraffine series.

The principal members of this series together with their chemical formulas are

Pentane, $C_5\ H_{12}$
Hexane, $C_6\ H_{14}$
Heptane, $C_7\ H_{16}$

The symbol $C_5\ H_{12}$ is the chemist's method of expressing the fact that the given substance is made up of molecules, each of which consists of five atoms of carbon and twelve of hydrogen. It will be noticed in this series that while the carbon atom increases by unity, the hydrogen element increases by two, hence we can write the general formula for the paraffine series thus:

$$Cn\ H2n+2n$$

We do not know what the third element may be in every instance but we do know it will consist of twice as many atoms as there are of carbon.

LESSON XIX.

Books devoted to the chemistry of petroleum and its products, fine gasoline as that portion of the crude that distills over betwe one hundred forty and one hundred fifty-eight degrees Fahrenhe Owing to the enormous demand for gasoline, caused by the autom bile and other gasoline engines, the refiners have found it necessa in order to keep ahead of the demand, to lower the grade. Ve little of the gasoline now on the market, therefore, will satisfy t definition given in the books. Instead of gasoline that shows Baumé test of seventy, or thereabouts, most of the gasoline used the present time tests in the neighborhood of sixty degrees. T time will undoubtedly come when it will not be possible to sup the demand with gasoline of even a sixty test, but before that ti comes we will see a more extended use of engines designed to the heavier fuels, such as kerosene, distillate and even crude oil. the present time, however, gasoline is the most important of the ternal combustion engine fuels.

In order to discuss the properties of gasoline or any other liq fuel intelligently, it will first be necessary to define a few of technical terms employed to describe its physical properties, the m important of which are: specific gravity, coefficient of expansi latent heat, heat value, viscosity, vapor tension and vapor densit

The specific gravity or density is obtained by comparing the wei of a given volume of the given liquid to an equal volume of w when the water is at thirty-nine degrees Fahrenheit, and the gi liquid is at sixty degrees. This quantity is obtained experiment by weighing equal volumes of the two liquids, at their proper t peratures and dividing the weight of the gasoline or other liquid the weight of the water. The quotient thus obtained is called specific gravity or density of the given liquid. The practical met of measuring density is by means of an instrument called an hyd meter. This is a glass instrument somewhat similar to a th mometer, having a graduated stem and weighted at the lower with mercury. When floated in water at a temperature of thi nine degrees it will sink to the zero mark on the stem. When floa in a lighter liquid like gasoline it will sink farther or until it places a volume of the liquid equal to the weight of the water. mark shown on the graduated stem can now be read directly will indicate the density or specific gravity. The specific gravity gasoline ranges between 0.636 and 0.700. Ordinarily, however, express density by another scale known as the Baumé scale. hydrometer used is called a Baumé hydrometer. While specific gr ity as above defined is always a decimal, usually expressed to the third decimal place, on the Baumé scale only whole numbers are used of two figures. It is because of this feature of simplicity that the Baumé scale is commonly accepted.

The following table shows the relation between the specific gravity and Baumé scale.

SPECIFIC GRAVITY	BAUME DEGREES	SPECIFIC GRAVITY	BAUME DEGREES
.755	56	.713	67
.751	57	.709	68
.747	58	.706	69
.743	59	.702	70
.739	60	.699	71
.735	61	.695	72
.731	62	.692	73
.727	63	.689	74
.724	64	.685	75
.720	65	.682	76
.717	66	.679	77
		.675	78

Knowing either the specific gravity or degrees Baumé it is easy to calculate the other by means of one or the other of the two following equations:

$$\text{Specific gravity} = \frac{140}{130 + \text{Degs. B.}} + .002$$

$$\text{Degrees Baumé} = \frac{140.26 - 130S}{S - .002}$$

These two equations give the specific gravity and degrees Baumé at the standard temperature of sixty degrees. S specific gravity.

The proper temperature at which to test gasoline with a hydrometer is sixty degrees, but it may be tested at any other temperature if the proper correction is made to the readings to reduce to the standard. Gasoline, like all other substances, expands with heat The proportional increase in volume in passing from sixty one to sixty-two degrees Fahrenheit is called *the coefficient of heat expansion*. The value of the coefficient is 0.0007, according to tests made by Dr. Watson. Expressed in fractional form 0.0007 equals [illegible] This means that if gasoline is heated one degree it increases in volume an amount equal to the ratio given.

Knowing this coefficient it becomes possible to take the specif gravity at any temperature and reduce the result to standard cond tions; for if we let *s* equal the specific gravity at any temperatu and s_{60} the specific gravity at sixty degrees

$$\text{then, } s=s_{60}[1-0.0007\ (s-60)]$$

The *heat value or thermal value* of any fuel represents the amou of heat which that fuel will liberate when burned in an atmosphe of oxygen. It is expressed in British thermal units, usually writt B. t. u. One B. t. u. is the amount of heat required to heat o pound of water from sixty-two to sixty-three degrees Fahrenhei Expressed in foot pounds one B. t. u. has the value of 778. The hea ing value of gasoline varies somewhat with its chemical compositio but is commonly accepted as 19,000 heat units. There is what known as a high thermal value and a low thermal value which we w discuss later.

The latent heat, literally hidden heat, is the amount of heat nece sary to transform one pound of the liquid when at the boiling poi into dry saturated vapor at that pressure. Latent heat is express in heat units and varies in accordance with the pressure at whi the transformation takes place. The higher the pressure, the high will be the boiling point and consequently the lower will be the late heat.

At ordinary temperatures gasoline will vaporize in the air, und atemospheric pressure. It draws its heat from the air. Ordina gasoline requires about one hundred forty heat units per pound f its vaporization, while water at atmospheric pressure requires 965 heat units. When the weather is quite cold it is evident that gas line will not vaporize because there is little heat in the air availab for the purpose. Thus it becomes necessary to heat the air at so point before it reaches the engine.

LESSON XX.

The specific heat of gasoline of 0.70 specific gravity is about 0.4 while that of water is unity. Thus it requires less than half as muc heat to raise gasoline to a given temperature as it does water. Hexan which boils at one hundred forty-three degrees under atmospheri ressure, must be heated one hundred eleven degrees above th ezing point of water. This requires $111\times.45=49.95$ heat unit practically fifty B. t. u. After reaching the boiling point it r ires only ninety heat units more to change a pound of it into vapo

Thus the entire heat of vaporization is, as stated in the last lesson, one hundred forty B. t. u. while that of a pound of water under similar conditions is 965.7 B. t. u. The different characteristics of the two liquids are thus brought out very clearly in considering their specific heats and heats of vaporization.

Consideration of the high heat of vaporization of water also reveals the reason why injecting it into the cylinder with the fuel helps cool the cylinder. The water itself is not a fuel. It absorbs a large amount of heat in being transformed into steam and carries this heat out in the exhaust in the form of steam. Every pound of steam passing out through the exhaust carries at least 965.7 B. t. u. It is sometimes claimed that the water is dissociated at the moment of explosion, that is, broken up into its constituent parts, hydrogen and oxygen. Under favorable conditions this may occur. If it does, a good deal more than 965.7 B. t. u. per pound must be absorbed. During the expansion of the gases the temperature in the cylinder will fall and the constituents of the water will again combine and in doing so liberate just as much heat as they absorbed in dissociation. Thus it would seem, if this action actually does take place, that there would be no loss finally, but rather a gain, since the initial temperature and pressure would be lower and the final higher than if water were not used at all. It is suspected such reactions take place, but it is not definitely known whether they do or not. While there is no question but that the heat used in dissociation is returned again on recombination, the fact must not be lost sight of that every pound of water emerging from the exhaust as steam, carries at least 965.7 B. t. u., while water at say seventy degrees, going into the cylinder, contains only twenty-eight heat units. Therefore, the heat of the fuel must impart to the water at least 937.7 B. t. u. which are carried away and do no useful work. The point we wish to make is this, no matter if recombination does take place, all the heat is not returned, but that part which is used up in vaporization of the steam in the beginning is lost. In view of the fact that the cylinder must be cooled in some manner anyway this is not considered a serious fault. Now let us return to a consideration of the properties of gasoline.

The *vapor tension* may be explained thus:—If gasoline be placed in a closed vessel and heated, the pressure, corresponding to any temperature, is the vapor tension. At the boiling point of the liquid, when exposed to the atmosphere in an open vessel, the vapor tension is 14.7 pounds per square inch. Vapor tension is measured from the zero of pressures; that is, it is equal to the gage pressure plus 14.7. At fifty degrees temperature gasoline of seventy-five degrees

Baumé gravity has a vapor tension of 2.53 pounds per square inch. In other words, if you could place a quantity of seventy-six degrees gasoline, at a temperature of fifty degrees in a perfect vacuum, the pressure would immediately rise to 2.53 pounds per square inch due to the vaporization of a part of the liquid. Different grades of gasoline show some variations in vapor tension under the same temperature conditions. For example, pentane has a vapor tension of 2.538; hexane, 3.053, and heptane of 3.547 pounds per square inch.

The *vapor density* is expressed as ratio of the weight of dry vapor as compared with an equal volume of dry air at the same temperature. In other words, if we divide the weight of a cubic foot of dry gasoline vapor by the weight of a cubic foot of dry air the quotient will represent the vapor density of gasoline. Gasoline vapor is heavy.

If a quantity of gasoline be spilled on the floor the vapor will spread along the floor and displace the air, but will not rise rapidly nor diffuse quickly through the air. Experiments show that the vapor density averages about 3.25, or in other words, that a cubic foot of gasoline vapor weighs about 3.25 times as much as a cubic foot of air. Now a cubic foot of air at sixty degrees and under atmospheric pressure weighs .0756 pounds, consequently a cubic foot of gasoline vapor will weigh $.0756 \times 3.25 = .2457$ or a trifle less than a quarter of a pound.

The last one of the properties mentioned in the last lesson is viscosity. It may be defined as that quality which determines the rapidity of flow of the liquid through a standard tubular opening under a given pressure or head. It has been determined by experiment that the rapidity of flow of any fluid through a small tube, whose length is relatively great as compared with its diameter, is inversely proportional to its viscosity. Stated in plainer terms, the greater the viscosity, the slower the flow. Molasses has very high viscosity; its particles adhere to each other, it does not readily fall in drops. Water, on the other hand, has very little viscosity. Gasoline has little viscosity, but the heavier oils, like lubricating oils, are very viscous.

Many tests have been made to determine the viscosity of gasoline under different conditions of temperature and the law governing viscosity has been pretty well established. This is important to the engineer who wishes to determine the weight of any particular grade of gasoline that will flow through a given nozzle in a certain length of time. With few exceptions viscosity increases with the density or weight and decreases uniformly as the temperature increases. A discussion of the mathematical laws involving viscosity are a little abstruse and will not be considered in these lessons. Let suffice to give two illustrations:

Density Baumé degrees. 59° Fah.	Viscosity.		
	31° Fah.	59°	87°
64	.00486	.00454	.00430
76	.00376	.00342	.00319

It will be observed that at a temperature of thirty-one degrees the viscosity of the sixty-four degree gasoline is nearly a third greater than the seventy-six, and, according to the law stated, it should flow through a given small tube only about three-fourths as fast.

Now let us turn back to a further consideration of heat and the heat value of fuels. This is important from the fact that the gas engine is a heat engine. A certain amount of heat is delivered to the engine in the form of fuel and its function is to set this heat free and transform as large a portion as possible into useful work. That engine which can accomplish this transformation with the least loss, is, of course, the best engine.

The heat value of the various petroleum fuels varies slightly with their chemical composition and, as stated in the previous lesson, is taken generally at 19,000 B. t. u. per pound. The difference of the heat value per pound does not vary greatly but per gallon there is a wide difference due to the differences in density. For example:—a gallon of high grade gasoline having an actual specific gravity of 0.636 weighs 5.31 pounds per gallon while kerosene, which has a specific gravity of 0.80, weighs 6.67 pounds per gallon. Considering a heat value of 19,000 B. t. u. per pound, gasoline would have 10,089,000 B. t. u. per gallon and the kerosene 12,673,000 B. t. u., or, about twenty-five per cent more heat per gallon.

LESSON XXI.

It has been stated several times in these lessons that combustion is a chemical process. This is a fundamental fact in gas engine operation that must never be lost sight of for the reason that one can not understand the changes that take place inside a gas engine cylinder without some knowledge of the chemistry of combustion. Atmospheric air consists of twenty-three parts by weight of oxygen and seventy-seven parts nitrogen. These figures are not exactly correct but are near enough. There are a few other gases usually present in minute quantities and a portion of watery vapor. For our pose, however, we will not enter into the refinements of the con tion of air but accept the figures given. Of the two gases menti oxygen is the only one that aids combustion, nitrogen acts mer a dilutent and a body or vehicle for the transmission of heat. line consists of carbon and hydrogen in varying porportions de ing upon its gravity. Both of these elements require oxygen in to carry out the process of combustion. When carbon burns it chemically with a definite quantity of oxygen, which proportio vary in only two ways. When combustion is complete, each at carbon unites with two of oxygen forming carbon dioxide gas (If there is not enough oxygen present, each atom of carbon will with only one of oxygen, thus forming carbon monoxide (CO), is a very poisonous gas. In uniting with oxygen to form CO_2 pound of carbon sets free 14,600 B. t. u., but when CO is f only 4,400 B. t. u. are liberated. There are two good reasons, fore, to endeavor to obtain complete combustion, one to obtai most heat and consequently the most work from the fuel an other to avoid the formation of poisonous gas. When hydrogen bines with oxygen each atom of oxygen unites with two of h gen, forming watery vapor, or, in the gas engine cylinder, stea chemical symbol for which is H_2O. When a pound of hyd burns there are set free 61,000 B. t. u. Hydrogen can combine oxygen in only the one way. Now all the oxygen that is used in bustion must come from the air, consequently it is essential t the air and fuel in proper proportions as it goes into the cyl This process is called carburetion, meaning carburetting the air is, charging it with carbon.

Since the air consists largely of nitrogen it requires a consid quantity in order to supply the correct amount of oxygen. In to simplify the calculations as to the amount of air needed consider hexane, whose chemical symbol is represented by th pression C_6H_{14}. This represents as near the chemical formu gasoline as we can obtain with one simple expression. The a weight of carbon is twelve and of hydrogen one, hence, the atomic weight of the molecule of gasoline is:

$6\times12=72$ of the carbon;
$14\times\ 1=14$ of hydrogen.

Total atomic weight=86

Or, reducing this to a percentage basis, 83.72 per cent of the f carbon and 16.28 per cent is hydrogen, by weight. In burning c

CO_2, and remembering that the atomic weight of oxygen is six-en, we find that the atomic weight of the CO_2 molecule may be und in this manner:

$$12C+32O=44CO_2.$$

e have simply added the atomic weights of the one atom of car-n and the two atoms of oxygen in arriving at the atomic weight of CO_2. In like manner we may find the atomic weight of the lecule of H_2O, thus:

$$2H+16O=18H_2O.$$

ese two expressions show at a glance the proportions, by weight, which the hydrogen and oxygen combine. Dividing the atomic ight of the oxygen by the atomic weight of the carbon in the CO_2 lecule we have: $\frac{32}{12}=2\frac{2}{3}$, thus showing that every pound of rbon requires two and two-third pounds of oxygen, and, in similar nner, $\frac{16}{2}=8$, which shows that every pound of hydrogen requires ht pounds of oxygen for complete combustion.

Since there are twenty-three pounds of oxygen in one hundred nds of air, in order to find how many pounds of air are required furnish two and two-third pounds of oxygen, we may form a pro-tion as follows:

3:100::2⅔:x. Solving this for x in the usual manner, we obtain 59 pounds of air for each pound of carbon. Returning to the rogen which takes eight pounds of oxygen per pound, and forming milar proportion, we find it requires 34.77 pounds of air for every nd of hydrogen. One pound of fuel, of the proportions given, t is 83.72 per cent carbon, and 16.28 per cent hydrogen, would re-re the following weights of air:

$$.8372\times11.56=9.70$$
$$.1628\times34.77=5.66$$

s making a total of 15.36 pounds.

One pound of carbon requires two and two-thirds pounds of oxygen, sequently there is formed by such reactions three and two-thirds nds of CO_2. But in burning 0.8372 of a pound, the weight of $_2$ formed is $3\frac{1}{2}\times.8372=3.0697$ pounds. While the amount of tery vapor formed is $.1628\times9=1.4652$ pounds. Summing up, we d the result of combustion of one pound of gasoline is:

1.465 pounds of watery vapor
3.096 pounds CO_2
10.676 pounds nitrogen

Total gas 15.237 pounds.

Since it is impossible to so intimately mix the fuel an bring every particle of fuel into intimate contact wit amount of oxygen it is necessary to supply an excess qua in order to obtain complete combustion. From eighteen pounds of air, therefore, must always be supplied for e of fuel. If this is not done, a certain portion of the fue to CO and the result will be a loss of power and poor eco

Now air can not very easily be measured by pounds s tomary to reduce the above quantity to cubic feet. A grees, and atmospheric pressure, a cubic foot of air weig a pound. Consequently to obtain the theoretical amo needed we must have $\frac{15.36}{.0756}=203$ cubic feet. Practicall use from 240 to 260 cubic feet.

We mentioned the fact in a previous lesson that a pou line will yield about 19,000 B. t. u. This is what is known heat value. If a pound of gasoline is burned in a calo the gases cooled down to sixty degrees Fah. we will obta heat value. If the gases are cooled only to 212 degr obtain the low heat value. The difference between the t explained by considering the latent heat of vaporization o resulting from the combustion of the hydrogen, and t sorbed by the CO_2 and the nitrogen. In the last lesson it out that the heat of vaporization of a pound of steam at is 965.7 B. t. u., but from sixty degrees to 212 degrees difference of 152 heat units. Hence above sixty degrees of steam at atmospheric pressure contains 1,117.7 heat have just seen that in burning one pound of gasoline there 1.465 pounds of water, consequently 1,117.7×1.465=1,637 required for the vaporization of the water and this quant must pass away with the exhaust, since at 212 degrees does not condense and give up its heat. There must be difference between the high heat value of gasoline and t sides which there is the heat of the CO_2 and of the nit taken into consideration in cooling from 212 degrees to or through a range of 152 degrees. The specific heat of and of nitrogen .244. The total heat given up by these per pound of fuel burned can now be calculated as follo

$$\begin{array}{lr}
 & 3.069\times.216\times152=100.67 \\
 & 10.676\times.244\times152=395.95 \\
\hline
 & 496.62 \\
\text{Adding the heat lost by water we have} & 1637.00 \\
\hline
\text{Giving a total of} \ldots\ldots\ldots\ldots & 2133.62 \text{ B. t. u.}
\end{array}$$

as the difference between the high and the low heat values of the gasoline. Some works on gas engines give one value and some the other. It is self evident that the only value the gas engineer is interested in is the low heat value because gas engines exhaust universally into the atmosphere, and all the heat contained in the gases below 212 degrees must be lost and will be lost unless some rational scheme is evolved to recover the heat in the exhaust gases. As a matter of fact much more heat than what we have mentioned is lost to the exhaust because the temperature of these gases as they emerge from the cylinder is considerably in excess of 212 degrees. This fact, however, has nothing to do with the method of figuring high and low heat values of the fuels. After considering the high heat value and making the necessary correction we generally assume a low heat value as given in the last lesson of 19,000 B. t. u. Theoretically, the low heat value should be higher as shown by the following computation:

14,600×.8372=12,223 B. t. u. liberated by the carbon.
61,000×.1628= 9,930 B. t. u. liberated by the hydrogen.

Total 22,153 B. t. u. liberated by one pound of fuel.

22,153—2,133=20,020, theoretical low heat value.

For practical purposes and on account of various losses the figure 19,000 is the one commonly used.

LESSON XXII.

Gasoline mixtures containing the correct proportions of air are easily ignited by an electric spark or incandescent piece of metal, but when the proportions vary outside of a certain rather narrow range they are difficult to ignite. It requires a greater quantity of heat to effect iginition and the combustion is not so rapid. This condition is the most frequent cause of backfiring with either lean or rich mixtures. The gas will remain burning in the cylinder even after the exhaust stroke has been completed, and thus ignite the incoming charge. At atmospheric pressure the richest mixture that will ignite is about one part gasoline to seven of air. The limit for lean mixtures is one of gasoline to thirty-two of air. Of course, with increased pressure, leaner mixtures may be readily ignited and burned.

In order to understand more clearly what takes place in the cylinder during combustion it will be necessary for us to consider some of the elements of thermo-dynamics or dynamics of heat. This is a rather difficult, abstruse subject and one generally approached by means of the integral calculus, but we will endeavor to present at least the principal facts by means of arithmetic and perhaps a little elementary algebra. In all cases it may not be possible to show how some of the expressions are derived and these will have to be taken for granted. With this brief introduction we will proceed.

As has been stated many times before, heat is a form of energy. Heat may be changed into any of the forms of mechanical energy or mechanical energy may be changed into heat. There are many familiar illustrations of this fact; for example, a drill or lathe tool will get very hot, showing that a part of the energy required to drive the drill is changed into heat. A dull drill will heat sooner than a sharp one because less of its energy is turned into work. A slipping brake gets very hot also. These are examples of mechanical energy being turned into heat. On the other hand, we are all familiar with the the action of an engine in turning the heat of fuel into work. Or, if we want to go farther, consider an engine driving an electric dynamo which generates electricity which is expended again as heat in the form of the electric arc. Here we have the complete cycle. Now, a definite quantity of heat will do a definite amount of work; in other words, an exact relationship exists between heat and work which may be expressed mathematically. Heat, which is a form of energy, can be changed to any other form but the amount will always be the same. In transforming energy from one form to another there can never be any increase because we are dealing with a definite quantity and that is the reason we can never construct a perpetual motion machine. If we could, then the law of the conservation of energy would not be true. A perpetual motion machine must create energy continuously in order to keep going, and this is contrary to our law which states that energy may be changed in form but can neither be created nor destroyed. We may dissipate energy and it may escape from us but it is never destroyed, neither can we by any act create it. These are the fundamental facts upon which the whole theory of heat engines is based.

Experiments conducted by Joule, Mayor Rowlands and others proved that energy is indestructible and showed the relationship between a heat unit and mechanical energy. According to the accepted standard at the present time, the mechanical equivalent of a heat unit is 778 foot pounds, which in most engineering works is represented by the letter J, meaning Joule. This means that the energy required to heat one pound of water from 62 to 63 degrees Fahrenheit

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CHAPTER VIII.

LAWS GOVERNING APPLICATION OF HEAT TO GASES.

LESSON XXIII.

The scale of temperature used in all engineering calculations differs considerably from what is used in everyday weather reports, thus making it necessary for us to look into the matter of temperature measurements in order to understand some of the computations.

The temperature of a body represents the intensity of heat. It is not in any sense a measure of the quantity of heat. There are two thermometers in general use, the Fahrenheit, which is used for all ordinary affairs, and the Centigrade, used in most all scientific work except in engineering. Engineers generally cling to the Fahrenheit scale although they frequently have to refer to the Centigrade and transform the readings of one thermometer into that of the other. The Fahrenheit thermometer has arbitrarily fixed the boiling point of water at a temperature of 212 degrees, and the freezing point of water at thirty-two degrees, under atmospheric pressure of 14.7 pounds. The distance between these two points in the scale is divided into one hundred eighty equal divisions called degrees. In some thermometers these degrees, of equal length are marked off above and below the two limits given.

In the Centigrade thermometer the freezing point of water is taken as zero, the boiling point 100 degrees and the space in between is divided into one hundred equal parts. The length of a degree Fahrenheit is therefore five-ninths of a degree Centigrade on the same scale. The illustration represents the two thermometers and shows how the degrees are marked off.

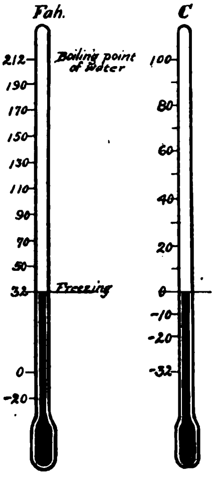

FIG. 23. A COMPARISON OF FAHRENHEIT AND CENTIGRADE THERMOMETER SCALES.

A little consideration of the diagram and the way the scales are constructed will make the following rules evident. *Rule I.* To cor

Baumé gravity has a vapor tension of 2.53 pounds per square inch. In other words, if you could place a quantity of seventy-six degrees gasoline, at a temperature of fifty degrees in a perfect vacuum, the pressure would immediately rise to 2.53 pounds per square inch due to the vaporization of a part of the liquid. Different grades of gasoline show some variations in vapor tension under the same temperature conditions. For example, pentane has a vapor tension of 2.538; hexane, 3.053, and heptane of 3.547 pounds per square inch.

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If a quantity of gasoline be spilled on the floor the vapor will spread along the floor and displace the air, but will not rise rapidly nor diffuse quickly through the air. Experiments show that the vapor density averages about 3.25, or in other words, that a cubic foot of gasoline vapor weighs about 3.25 times as much as a cubic foot of air. Now a cubic foot of air at sixty degrees and under atmospheric pressure weighs .0756 pounds, consequently a cubic foot of gasoline vapor will weigh $.0756 \times 3.25 = .2457$ or a trifle less than a quarter of a pound.

The last one of the properties mentioned in the last lesson is viscosity. It may be defined as that quality which determines the rapidity of flow of the liquid through a standard tubular opening under a given pressure or head. It has been determined by experiment that the rapidity of flow of any fluid through a small tube, whose length is relatively great as compared with its diameter, is inversely proportional to its viscosity. Stated in plainer terms, the greater the viscosity, the slower the flow. Molasses has very high viscosity; its particles adhere to each other, it does not readily fall in drops. Water, on the other hand, has very little viscosity. Gasoline has little viscosity, but the heavier oils, like lubricating oils, are very viscous.

Many tests have been made to determine the viscosity of gasoline under different conditions of temperature and the law governing viscosity has been pretty well established. This is important to the engineer who wishes to determine the weight of any particular grade of gasoline that will flow through a given nozzle in a certain length of time. With few exceptions viscosity increases with the density or weight and decreases uniformly as the temperature increases. A discussion of the mathematical laws involving viscosity are a little abstruse and will not be considered in these lessons. Let suffice to give two illustrations:

Density Baumé degrees. 59° Fah.	Viscosity.		
	31° Fah.	59°	87°
64	.00486	.00454	.00430
76	.00376	.00342	.00319

It will be observed that at a temperature of thirty-one degrees the viscosity of the sixty-four degree gasoline is nearly a third greater than the seventy-six. and, according to the law stated, it should flow through a given small tube only about three-fourths as fast.

Now let us turn back to a further consideration of heat and the heat value of fuels. This is important from the fact that the gas engine is a heat engine. A certain amount of heat is delivered to the engine in the form of fuel and its function is to set this heat free and transform as large a portion as possible into useful work. That engine which can accomplish this transformation with the least loss, is, of course, the best engine.

The heat value of the various petroleum fuels varies slightly with their chemical composition and, as stated in the previous lesson, is taken generally at 19,000 B. t. u. per pound. The difference of the heat value per pound does not vary greatly but per gallon there is a wide difference due to the difference in density. For example:—a gallon of high grade gasoline having an actual specific gravity of 0.638 weighs 5.31 pounds per gallon while kerosene, which has a specific gravity of 0.80, weighs 6.67 pounds per gallon. Considering a heat value of 19,000 B. t. u. per pound, gasoline would have 10,089,000 B. t. u. per gallon and the kerosene 12,673,000 B. t. u. or, about twenty-five per cent more heat per gallon.

LESSON XXI.

It has been stated several times in these lessons that combustion is a chemical process. This is a fundamental fact in gas engine operation that must never be lost sight of for the reason that one can not understand the changes that take place inside a gas engine cylinder without some knowledge of the chemistry of combustion. Atmospheric air consists of twenty-three parts by weight of oxygen and seventy-seven parts nitrogen. These figures are not exactly correct but are near enough. There are a few other gases usually present in minute quantities and a portion of watery vapor. For our purpose, however, we will not enter into the refinements of the composition of air but accept the figures given. Of the two gases mentioned, oxygen is the only one that aids combustion, nitrogen acts merely as a dilutent and a body or vehicle for the transmission of heat. Gasoline consists of carbon and hydrogen in varying porportions depending upon its gravity. Both of these elements require oxygen in order to carry out the process of combustion. When carbon burns it unites chemically with a definite quantity of oxygen, which proportion can vary in only two ways. When combustion is complete, each atom of carbon unites with two of oxygen forming carbon dioxide gas (CO_2). If there is not enough oxygen present, each atom of carbon will unite with only one of oxygen, thus forming carbon monoxide (CO), which is a very poisonous gas. In uniting with oxygen to form CO_2 each pound of carbon sets free 14,600 B. t. u., but when CO is formed only 4,400 B. t. u. are liberated. There are two good reasons, therefore, to endeavor to obtain complete combustion, one to obtain the most heat and consequently the most work from the fuel and the other to avoid the formation of poisonous gas. When hydrogen combines with oxygen each atom of oxygen unites with two of hydrogen, forming watery vapor, or, in the gas engine cylinder, steam, the chemical symbol for which is H_2O. When a pound of hydrogen burns there are set free 61,000 B. t. u. Hydrogen can combine with oxygen in only the one way. Now all the oxygen that is used in combustion must come from the air, consequently it is essential to mix the air and fuel in proper proportions as it goes into the cylinder. This process is called carburetion, meaning carburetting the air, that is, charging it with carbon.

Since the air consists largely of nitrogen it requires a considerable quantity in order to supply the correct amount of oxygen. In order to simplify the calculations as to the amount of air needed let us consider hexane, whose chemical symbol is represented by the expression C_6H_{14}. This represents as near the chemical formula of gasoline as we can obtain with one simple expression. The atomic weight of carbon is twelve and of hydrogen one, hence, the total atomic weight of the molecule of gasoline is:

6×12=72 of the carbon;
14× 1=14 of hydrogen.

Total atomic weight=86

r, reducing this to a percentage basis, 83.72 per cent of the fuel is arbon and 16.28 per cent is hydrogen, by weight. In burning carbon to CO_2, and remembering that the atomic weight of oxygen is sixteen, we find that the atomic weight of the CO_2 molecule may be found in this manner:

$$12C+32O=44CO_2.$$

We have simply added the atomic weights of the one atom of carbon and the two atoms of oxygen in arriving at the atomic weight of the CO_2. In like manner we may find the atomic weight of the molecule of H_2O, thus:

$$2H+16O=18H_2O.$$

These two expressions show at a glance the proportions by weight in which the hydrogen and oxygen combine. Dividing the atomic weight of the oxygen by the atomic weight of the carbon in the CO_2 molecule we have: $\frac{32}{12}=2\frac{2}{3}$, thus showing that every pound of carbon requires two and two-third pounds of oxygen, and, in similar manner, $\frac{16}{2}=8$, which shows that every pound of hydrogen requires eight pounds of oxygen for complete combustion.

Since there are twenty-three pounds of oxygen in one hundred pounds of air, in order to find how many pounds of air are required to furnish two and two-third pounds of oxygen, we may form a proportion as follows:

$23:100::2\frac{2}{3}:x$. Solving this for x in the usual manner, we obtain 11.59 pounds of air for each pound of carbon. Returning to the hydrogen which takes eight pounds of oxygen per pound, and forming a similar proportion, we find it requires 34.77 pounds of air for every pound of hydrogen. One pound of fuel, of the proportions given, that is 83.72 per cent carbon, and 16.28 per cent hydrogen, would require the following weights of air:

$$.8372\times 11.56=9.70$$
$$.1628\times 34.77=5.66$$

thus making a total of 15.36 pounds.

One pound of carbon requires two and two-third pounds of oxygen, consequently there is formed by each pound three and two-third pounds of CO_2. But in burning 1 pound of fuel the weight of CO_2 formed is $3\frac{2}{3}\times.8372=3.069$ pounds, and the amount of watery vapor formed is $.1628\times 9=1.465$ pounds [illegible] find the result of [illegible] pound [illegible]

1.465 pounds of watery vapor
3.069 pounds of CO_2
[illegible] pounds of [illegible]

Total gas [illegible]

Since it is impossible to so intimately mix the fuel and air bring every particle of fuel into intimate contact with the amount of oxygen it is necessary to supply an excess quantity in order to obtain complete combustion. From eighteen to t pounds of air, therefore, must always be supplied for every of fuel. If this is not done, a certain portion of the fuel wil to CO and the result will be a loss of power and poor economy.

Now air can not very easily be measured by pounds so it i tomary to reduce the above quantity to cubic feet. At six grees, and atmospheric pressure, a cubic foot of air weighs .0 a pound. Consequently to obtain the theoretical amount needed we must have $\frac{15.36}{.0756}=203$ cubic feet. Practically we use from 240 to 260 cubic feet.

We mentioned the fact in a previous lesson that a pound of line will yield about 19,000 B. t. u. This is what is known as t heat value. If a pound of gasoline is burned in a calorimet the gases cooled down to sixty degrees Fah. we will obtain th heat value. If the gases are cooled only to 212 degrees w obtain the low heat value. The difference between the two m explained by considering the latent heat of vaporization of the resulting from the combustion of the hydrogen, and the he sorbed by the CO_2 and the nitrogen. In the last lesson it was p out that the heat of vaporization of a pound of steam at 212 d is 965.7 B. t. u., but from sixty degrees to 212 degrees ther difference of 152 heat units. Hence above sixty degrees each of steam at atmospheric pressure contains 1,117.7 heat units. have just seen that in burning one pound of gasoline there are f 1.465 pounds of water, consequently 1,117.7×1.465=1,637 B. t. required for the vaporization of the water and this quantity o must pass away with the exhaust, since at 212 degrees the does not condense and give up its heat. There must be that difference between the high heat value of gasoline and the lo sides which there is the heat of the CO_2 and of the nitrogen taken into consideration in cooling from 212 degrees to 60 d or through a range of 152 degrees. The specific heat of CO_2 i and of nitrogen .244. The total heat given up by these two per pound of fuel burned can now be calculated as follows:

$$3.069\times.216\times152=100.67$$
$$10.676\times.244\times152=395.95$$

496.62

Adding the heat lost by water we have 1637.00

Giving a total of............. 2133.62 B. t. u.

as the difference between the high and the low heat values of the gasoline. Some works on gas engines give one value and some the other. It is self evident that the only value the gas engineer is interested in is the low heat value because gas engines exhaust universally into the atmosphere, and all the heat contained in the gases below 212 degrees must be lost and will be lost unless some rational scheme is evolved to recover the heat in the exhaust gases. As a matter of fact much more heat than what we have mentioned is lost to the exhaust because the temperature of these gases as they emerge from the cylinder is considerably in excess of 212 degrees. This fact, however, has nothing to do with the method of figuring high and low heat values of the fuels. After considering the high heat value and making the necessary correction we generally assume a low heat value as given in the last lesson of 19,000 B. t. u. Theoretically, the low heat value should be higher as shown by the following computation:

14,600×.8372=12,223 B. t. u. liberated by the carbon.
61,000×.1628= 9,930 B. t. u. liberated by the hydrogen.

Total 22,153 B. t. u. liberated by one pound of fuel.

22,153—2,133=20,020, theoretical low heat value.

For practical purposes and on account of various losses the figure 19,000 is the one commonly used.

LESSON XXII.

Gasoline mixtures containing the correct proportions of air are easily ignited by an electric spark or incandescent piece of metal, but when the proportions vary outside of a certain rather narrow range they are difficult to ignite. It requires a greater quantity of heat to effect iginition and the combustion is not so rapid. This condition is the most frequent cause of backfiring with either lean or rich mixtures. The gas will remain burning in the cylinder even after the exhaust stroke has been completed, and thus ignite the incoming charge. At atmospheric pressure the richest mixture that will ignite is about one part gas [illegible] seven of air. The limit for lean mixtures is one of gas [illegible] of air. Of course with increased pressure, leaner mixtures may be readily ignited and burned.

In order to understand more clearly what takes place in the cylinder during combustion [illegible] the elements of thermo-dynamics or dynamics of heat. This is a rather difficult, abstruse subject and one generally approached by means of the integral calculus, but we will endeavor to present at least the principal facts by means of arithmetic and perhaps a little elementary algebra. In all cases it may not be possible to show how some of the expressions are derived and these will have to be taken for granted. With this brief introduction we will proceed.

As has been stated many times before, heat is a form of energy. Heat may be changed into any of the forms of mechanical energy or mechanical energy may be changed into heat. There are many familiar illustrations of this fact; for example, a drill or lathe tool will get very hot, showing that a part of the energy required to drive the drill is changed into heat. A dull drill will heat sooner than a sharp one because less of its energy is turned into work. A slipping brake gets very hot also. These are examples of mechanical energy being turned into heat. On the other hand, we are all familiar with the the action of an engine in turning the heat of fuel into work. Or, if we want to go farther, consider an engine driving an electric dynamo which generates electricity which is expended again as heat in the form of the electric arc. Here we have the complete cycle. Now, a definite quantity of heat will do a definite amount of work; in other words, an exact relationship exists between heat and work which may be expressed mathematically. Heat, which is a form of energy, can be changed to any other form but the amount will always be the same. In transforming energy from one form to another there can never be any increase because we are dealing with a definite quantity and that is the reason we can never construct a perpetual motion machine. If we could, then the law of the conservation of energy would not be true. A perpetual motion machine must create energy continuously in order to keep going, and this is contrary to our law which states that energy may be changed in form but can neither be created nor destroyed. We may dissipate energy and it may escape from us but it is never destroyed, neither can we by any act create it. These are the fundamental facts upon which the whole theory of heat engines is based.

Experiments conducted by Joule, Mayor Rowlands and others proved that energy is indestructible and showed the relationship between a heat unit and mechanical energy. According to the accepted standard at the present time, the mechanical equivalent of a heat unit is 778 foot pounds, which in most engineering works is represented by the letter J, meaning Joule. This means that the energy required to heat one pound of water from 62 to 63 degrees Fahrenheit is equivalent to raising a weight of 778 pounds one foot high. Therefore, we may write,

1. B. T. U.=778 foot pounds=J.

The broad underlying principles involved in converting heat into work and the reciprocal process of converting work into heat are embodied in two laws known respectively as the first and second laws of thermo-dynamics which are generally expressed as follows:

First Law of Thermo-dynamics.—The conversion of heat into work, or, conversely, of work into heat, takes place in a definite ratio.

Second Law of Thermo-dynamics.—If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts, the effects of these parts in causing the work to be performed are equal. (Rankine.)

The working media of all heat engines are either gases or vapors which strongly resemble gases in their behavior; consequently, the next step must be a consideration of gases and their properties. It has been found advantageous to distinguish between a perfect gas and imperfect gases or vapors. A perfect gas is an ideal substance which will remain a gas at all temperatures and at all pressures. Gases, like oxygen, hydrogen and nitrogen, approach the ideal form but can be liquified or even solidified under certain conditions. Steam under high temperature behaves near enough like a perfect gas so that the laws apply and so also do the gases which occur during combustion in a gas engine cylinder. Our laws of gases are based on the assumption that there is a perfect gas and the laws deduced are found to apply with very slight correction to the gases and vapors with which we are familiar. It has been found that if a gas is confined in a closed vessel it will exert a uniform pressure on every side of that vessel; also, if the volume of the gas is decreased by a certain amount through compression, and the temperature remains constant, the pressure will increase inversely as the volume. On the other hand, if the volume is increased under the same conditions the pressure will fall in proportion to the increase in volume. In other words, if the absolute pressure in a cylinder is twenty pounds and the volume is halved, the pressure will rise to forty pounds if the temperature remains constant. This is known as Marriotte's law of gases. We can express this law mathematically by the formula.

$$P V = C.$$

where P equals the absolute pressure in pounds, V the volume, and C a constant. The formula merely states that the product of the pressure and volume is constant, no matter how either varies, provided they are dependent upon each other. When the temperature remains constant it is spoken of as either isothermal expansion or compression, meaning with equal heat. As neither expansion nor compression takes place ordinarily isothermally, this will need further explanation in a succeeding lesson.

CHAPTER VIII.

LAWS GOVERNING APPLICATION OF HEAT TO GASES.

LESSON XXIII.

The scale of temperature used in all engineering calculations differs considerably from what is used in everyday weather reports, thus making it necessary for us to look into the matter of temperature measurements in order to understand some of the computations.

The temperature of a body represents the intensity of heat. It is not in any sense a measure of the quantity of heat. There are two thermometers in general use, the Fahrenheit, which is used for all ordinary affairs, and the Centigrade, used in most all scientific work except in engineering. Engineers generally cling to the Fahrenheit scale although they frequently have to refer to the Centigrade and transform the readings of one thermometer into that of the other. The Fahrenheit thermometer has arbitrarily fixed the boiling point of water at a temperature of 212 degrees, and the freezing point of water at thirty-two degrees, under atmospheric pressure of 14.7 pounds. The distance between these two points in the scale is divided into one hundred eighty equal divisions called degrees. In some thermometers these degrees, of equal length are marked off above and below the two limits given.

In the Centigrade thermometer the freezing point of water is taken as zero, the boiling point 100 degrees and the space in between is divided into one hundred equal parts. The length of a degree Fahrenheit is therefore five-ninths of a degree Centigrade on the same scale. The illustration represents the two thermometers and shows how the degrees are marked off.

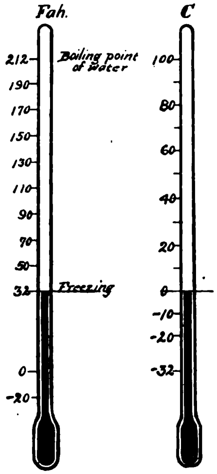


FIG. 23. A COMPARISON OF FAHRENHEIT AND CENTIGRADE THERMOMETER SCALES.

A little consideration of the diagram and the way the scales are constructed will make the following rules evident. *Rule I.* To convert degrees Fahrenheit into degrees Centigrade: Subtract thirty-two from the Fahrenheit reading, multiply the remainder by five, and divide by nine. The result will be the corresponding Centigrade temperature. For example, change 104 degrees Fahrenheit to Centigrade:

$104-32=72.$
$72\times5=360;\ 360\div9=40$ degrees C.

Rule II. To change Centigrade degrees into Fahrenheit: Multiply by nine, divide by five, and add thirty-two. For example: Change 15 degrees Centigrade to Fahrenheit.

$15\times9=135;\ 135\div5=27.$
$27+32=59$ degrees Fahrenheit.

In engineering practice while we use either one of the two thermometers in our experimental work we always reduce to Fahrenheit degrees and use what is called the *absolute scale.* The absolute temperature scale is based on the behavior of an ideal gas. If a gas, say air, is heated, it will expand, unless restrained, and a certain relation has been found to exist between the increase of temperature and the increase of volume. It has been found that if we take one cubic foot of any gas at zero Fahrenheit and cool it one degree and keep the temperature constant it will shrink 1/461 of its original volume. The rate of decrease or increase for equal changes of temperature is found to be constant, within very close limits and would apparently be exact for a perfect gas. Accordingly, if a gas were cooled 461 degrees below zero of the Fahrenheit scale it would not have any heat left, if we assume that heat is a form of molecular energy, because at that temperature the gas would cease to exist as such.

Since in engineering we are always engaged in measuring heat quantities, it is necessary for us to start with the zero of heat and in order to do so we must measure zero from a point where no heat exists. This point according to the foregoing discussion is 461 degrees below zero of our Fahrenheit scale and that point is taken as absolute zero.

Therefore in order to change the reading of the Fahrenheit thermometer to the absolute scale all we need to do is to add 461 degrees. For example, 70 degrees on a Fahrenheit thermometer would correspond to $70+461=521$ degrees absolute.

The relation between pressure, volume and temperature of a gas can now be expressed mathematically by the formula: P.V.=R.T., where P represents the absolute pressure in pounds; V, the volume in cubic feet; R, a constant numerical quantity which varies according to the gas under discussion; and T, is the absolute temperature.

The formula merely states that the product of the pressure and volume is equal to some constant multiplied by the absolute temperature of the gas. This is known as *Charles' Law.*

Specific Heats. In the definition given of specific heat in a former lesson it was pointed out that water has a specific heat of unity and that if one pound of water be heated from 62 to 63 degrees Fahrenheit, the amount of heat required would amount to one heat unit. If we should heat a body weighing one pound through one degree and it had a specific heat of only one-half it would require only one-half a heat unit. From this we see that the total heat expended upon a body to raise it to a given temperature may be calculated by multiplying its weight, specific heat and the increase in temperature together. For example: How much heat is required to raise twenty-five pounds of air having a specific heat of .2375 from 40 to 70 degrees Fahrenheit? Solution: $25\times.2375\times30=178.12$ heat units. The heat required to raise any substance through any given range in temperature may be calculated in a similar manner if its specific heat is known.

In the case of a gas, however, much depends upon whether the gas is heated at constant pressure or at constant volume. This may be conveniently illustrated by considering a cylinder having a cross sectional area of one square foot and filled to a height of one foot with gas. Suppose the cylinder is fitted with an air tight piston, without weight and capable of moving without friction. There will be just one cubic foot of air in the cylinder. Now suppose heat is applied until the piston moves upward just one foot. The volume of the gas will be just doubled. In moving from its first position to the second the piston has moved just one foot. There has been a pressure of 14.7 pounds on each square inch, making a total load on the piston of $114\times14.7=2116.8$ pounds, due to atmospheric pressure. The total distance moved is one foot, therefore the total work done is 2116.8 foot pounds. This represents:

$$\frac{2116.8}{778}=2.721 \text{ heat units.}$$

The weight of a cubic foot of air at 62 degrees Fahrenheit and atmospheric pressure is 0.0761 pounds. In order to double the volume its temperature had to be doubled. 62 degrees Fahrenheit correspond to 523 degrees absolute, consequently its temperature increase was 523 degrees. The amount of heat required per pound of air per degree Fahrenheit to overcome the pressure of the air, was therefore:

$$\frac{0.0761\times523}{2.721}=0.0684 \text{ heat units.}$$

Experiments by Regnault show that in order to heat the air alone through this range of temperature requires 0.169 heat units if no work is done, that is, if the heating is done at constant volume. But when the heating is done at constant pressure in the manner described, the total heat used per pound of air per degree Fahrenheit is $0.0684+0.169=0.2374$ heat units. This latter quantity is called the specific heat of air at constant pressure, and is written very often in engineering works Cp, while the specific heat at constant volume is designated Cv. For air, $Cp=0.2374$ and $Cv=0.169$.

LESSON XXIV.

The specific heat of air at constant pressure, as shown in the last lesson, is 0.2374; and at constant volume 0.169. The ratio of these two specific heats is

$$\frac{Cp}{Cv}=\frac{0.2374}{0.169}=1.408$$

The value of this ratio changes somewhat at high temperatures, but in just what manner is not very well understood. Computations made from gas engine cards show values as low as 1.2. For most computations a value of 1.3 is assumed. The significance of this number will be shown presently.

Remembering the definition given to the term specific heat and representing the initial and final absolute temperatures by T and T_1 respectively, it is clear that the amount of heat required to heat a cubic foot of gas from T to T_1 degrees at constant volume may be represented by the expression

$$Cv(T_1—T)$$

The total work done if the gas is heated at constant pressure as illustrated in the last lesson by a piston without weight acting against atmospheric pressure is

$$Cp(T_1—T)$$

The external work done will be represented by the difference between these expressions, or

$$(Cp—Cv)\quad(T_1—T)$$

This work may be expressed in foot pounds by multiplying the pressure in pounds by the distance passed through in feet. Since the piston is one square foot in area, this distance represents volume in cubic feet, hence we can write

$$P(V_1-V)$$

external work done in foot pounds where V_1 and V represent the final and initial volumes respectively. Consequently

$$(Cp-Cv)\ (T_1-T)=\frac{P}{J}\,(V_1-V) \quad (a)$$

From Mariotte's law we know that if the pressure is constant the volume varies directly as the absolute temperature hence we can write

$$\frac{V}{T}=\frac{V_1}{T_1}$$

therefore $V_1=\frac{V\ T_1}{T}$

If we substitute this value of V_1 in equation (a) we obtain

$$(Cp-Cv)\ (T_1-T)=\frac{P}{J}\,(T_1\frac{V}{T}-V)$$

If we divide both sides of this expression by the common factor

$$\frac{T_1-T}{T} \quad \text{we have}$$

$$(Cp-Cv)\ T=\frac{PV}{J} \text{ or } J\ (Cp-Cv)=\frac{PV}{T}$$

Now $J=778$ and $(Cp-Cv)=(.2374-169)=.0684$.

Substituting values we have:—$778\times.0684=53.2=\frac{PV}{T}$

In other words, the pressure times the volume of air divided by its absolute temperature always equals the constant quantity 53.2. This constant is frequently referred to as R. It differs in value for different gases. We may now write

$$PV=RT$$

which expresses one of the fundamental laws of gases. We have thus derived, by very simple algebraic means, the principal relation that exists between the pressure, volume and temperature of a gas.

Adiabatic Changes.—If no heat is added to or subtracted from a given volume of gas during a change of state, the change is referred to as adiabatic. It follows from this definition that the useful work done by a gas during an adiabatic expansion is done at the expense of the energy already contained in the gas. For example, after ignition in a gas engine cylinder, the expansion is almost adiabatic.

There is some loss of heat to the cylinder walls and perhaps a little after-burning but these two in general offset each other so that the net result is that of adiabatic expansion. A mathematical discussion of the heat changes in an adiabatic expnsion requires the use of higher mathematics to show how the terms are derived, so we will pass that up and simply give the final results. The relations between pressure volume and temperature are

$$PV^k=TV^{k-1}=\frac{T^k}{P^{k-1}}$$

These are the relations existing between the three variables, pressure, volume and temperature, during an adiabatic change. These formulas are used in determining the compression volume for a predetermined compression pressure. They are used to determine the rise in temperature in compressing from one volume to another. In short; they are the fundamental formulas used in all computations relating to the change of state of air or any gas either in compressors or in gas engines.

It must be remembered that the values given for Cp and Cv were for air only. Other gases have different values which must be used in computing their change of state. In gas engine work it is customary and, for ordinary purposes sufficient, to use the values given for air for all compression changes but during expansion following ignition $k=1.3$ is usually used.

The products of combustion consist of a mixture of several gases, including nitrogen, carbon dioxide, some carbon monoxide, and steam. The specific heat, Cp, of the mixture may be assumed as 0.20 or possibly a little higher. If we assume that one part of gasoline requires twenty of air and that a pound of fuel contains 19,000 B. t. u. then the temperature of the twenty-one pounds of mixture at the end of combustion will be found as follows:

$$\frac{19,000}{.20\times21}=4500 \text{ degrees.}$$

Temperatures as high as this are never found in a gas engine cylinder. In fact, three thousand degrees is about as high as we have found by experimental methods. The discrepancy between theory and practice may be due in part to lack of knowledge in regard to specific heats at high temperatures, in part to the cooling action of the cylinder walls and in part to errors in measuring temperatures. It is also suggested that the dissociation of watery vapor and carbonic acid gas lowers the initial temperature and is responsible for some of the difference.

LESSON XXV.

It was shown in the last lesson that $PV^k=$ a constant where P and V represent any pressure and any volume. Consequently $P_1V_1{}^k$ or $P_2V_2{}^k=$ a constant; hence, we may write $P_1V_1{}^k=P_2V_2{}^k$ for any adiabatic change involving pressure and volume. This expression is the one used in determining the volume of the compression space corresponding to any given final and initial pressures. For example, suppose we wish to design a 6x8 cylinder with a compression pressure for seventy-five pounds absolute or a little more than sixty pounds gage. How large should be the compression volume? Since the engine is not a high speed machine it is permissible to assume that the absolute pressure in the cylinder at the end of the charging stroke P_1 is fourteen pounds.

From the formula above,

$$P_2=P_1\left(\frac{V_1}{V_2}\right)^k$$

in which everything is known except $\frac{V_1}{V_2}$ or the ratio of the total to the final volume.

Substituting numerical values we have:

$$75=14\left(\frac{V_1}{V_2}\right)^{1.3}.$$

$$\text{or}\qquad 5.357=\left(\frac{V_1}{V_2}\right)^{1.3}$$

The only way to solve an equation of this kind is by means of logarithms. Solving for $\frac{V_1}{V_2}$ we have

$$\log.\ 5.357=1.3\times\log.\left(\frac{V_1}{V_2}\right)$$

$$.728922=1.3\times\log.\left(\frac{V_1}{V_2}\right)$$

$$\text{From which}\qquad .5684=\log.\left(\frac{V_1}{V_2}\right)$$

$$\text{whence } \frac{V_1}{V_2}=3.64$$

In other words, the total volume divided by the compression volume =3.64. If we consider simply a cylindrical volume six inches in diameter, including the compression space, then we have,

$$\frac{8+V_2}{V_2}=3.64$$

$$\text{whence} \quad V_2=3$$

The total length of such cylinder would, therefore, be eleven inches.

The rise in temperature by compression may also be found by using one of these fundamental equations. For example, in compressing air from fourteen pounds to seventy-five pounds, with the temperature of the air initially at 70° Fah. or 531 degrees absolute. From the last lesson we know that

$$\frac{T^k}{P^{k-1}}=\frac{T_1^k}{P_1^{k-1}}$$

therefore

$$\frac{T_1}{T}=\left(\frac{P_1}{P}\right)^{\frac{k-1}{k}}$$

where T and P represent the pressure and temperature respectively at the end of the compression stroke.

Introducing numerical values into the above equation, and using 1.4 for k since the gas is air and at moderate temperature we have:

$$\frac{T_1}{531}=\left(\frac{14}{75}\right)^{.2857}$$

Using logarithms and solving we find T=841° absolute, or 380° Fahrenheit. The actual cylinder temperature at compression will be higher because of the heat absorbed from the hot cylinder walls, but just how much will be absorbed cannot be definitely determined.

The efficiency of any machine may be represented by a fraction, the denominator of which expresses the total energy supplied while the numerator expresses the amount utilized. The value of this fraction is, of course, always less than unity because no machine can utilize all the energy supplied and no machine can create energy.

thermal efficiency of a gas engine is the ratio of the heat utilized e heat supplied, or expressed as a formula:

$$E=\frac{\text{heat supplied}-\text{heat rejected}}{\text{heat supplied}}$$

rring to the diagram of an Otto cycle engine, figure 24, heat is lied from P_1 to P_2 and rejected from P_3 to P. The letter T

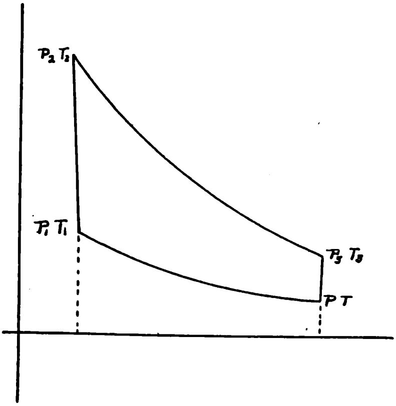


FIG. 24. DIAGRAM SHOWING PRESSURE AND TEMPERATURE CHANGES OF OTTO CYCLE.

its various subscripts, represents the absolute temperature of the at various parts of the cycle. Remembering and applying the itions of specific heat, we may write,

$$E=\frac{Cv\ (T_2-T_1)-Cv\ (T_3-T)}{Cv\ (T_2-T_1)}=1-\left(\frac{T_3-T}{T_2-T_1}\right)$$

actoring out Cv.

e heat supplied is what is derived from burning the fuel or in ng from T_1 to T_2. The heat rejected is what escapes at the ex- t, represented by $Cv(T_3-T)$ in the formula. The heat efficiency w expressed in terms of temperature and specific heats. Since re dealing with adiabatic expansion and compression, the three ssions deduced in the last lesson hold true for this case, therefore,

$$T\,V^{k-1}=T_1V_1^{k-1}=T_2V_2^{k-1} \text{ and}$$

$$\frac{T_1}{T}=\frac{T_2}{T_3}=\left(\frac{V}{V_1}\right)^{k-1}$$

But $T_3 = \frac{T_2}{T_1} T$, which value may be substituted in the formul efficiency; then, by factoring out of numerator and denominato quantity $\frac{T_2}{T_1} - 1$ we obtain:

$$E = 1 - \frac{T}{T_1} = 1 - \left(\frac{V_1}{V}\right)^{k-1} = 1 - \left(\frac{1}{r}\right)^{k-1}$$

But $\frac{V_1}{V}$ = the ratio of clearance volume to total volume and ma written $\frac{1}{r}$, and since k for gasoline engines equals 1.3 we have fi

$$E = 1 - \left(\frac{1}{r}\right)^{.3}$$

It is evident that as r increases, the value of the fraction of whi is a part will decrease and E will increase. In other words, we proved that with high compression ratios the efficiency incre This can be easily demonstrated by choosing values of three, and five for the ratio r and computing the theoretical efficienc the different cases.

It is not intended in this series of lessons to give an extended c in the mathematical heat theory of gas engines but the ques herein discussed are asked so frequently that the writer thoug advisable to show how some of the values are obtained. The m matics of the subject is very difficult and of slight value exce the experimenter or designer. Even the latter makes little use o higher mathematics but depends mainly upon tables made up e from his own experience or the experience of others; neverthele requires just such a study as we have briefly suggested to put steam and gas engineering on a firm scientific basis. It showe signers where they were right and in what direction they would the easiest field for improvement.

CHAPTER IX

LUBRICATION, LUBRICANTS, LUBRICATORS.

LESSON XXVI.

Lubrication.—Lack of lubrication for a few brief moments will ruin the finest engine made. In fact, the finer it is made and the better all friction surfaces are fitted, the greater the extent of the damage. Metal must not rub directly on metal, is the fundamental principle of lubrication. Whenever metal surfaces rub together, no matter how perfectly they have been fitted, heat will be generated by the friction. The parts in contact expand, making friction greater, and in a short time the heat becomes great enough to cause the surface to soften and then abrasion begins. It doesn't take long until the rubbing surfaces begin to cut and in an incredibly short time the bearings are ruined. Often the bearing and moving part fuse together and stop the motor. This happens frequently when bronze bearings are run dry. Babbitt, being softer, will melt and run out, but even this, soft as it is, will cut the shaft, making redressing necessary.

It is not an easy matter to repair a badly cut shaft even with the facilities of a good shop. The usual method of repairing is with a file, but no matter how carefully the work be done it will not be as good as it was originally. The rough outer surface can be made reasonably smooth but the grooves can not be filed out. If they are at all numerous the bearing surface is reduced in area by just that amount and the consequent load per unit area is accordingly increased. This increase of load on the remaining portion makes lubrication more difficult, for the heavier the load on a bearing the greater the liability of squeezing all the oil out, thus permitting metallic contact. The oil forms a thin film between the parts upon which the shaft, piston, or other moving parts rest or slide. The fine oil globules support the moving parts somewhat like the balls in a ball bearing. They roll and slide easily without much friction either between each other or between themselves and the metal. Consequently it does not require much work to overcome the friction of a well oiled bearing, and if there is not much friction there will be very little heat and the bearing will run cool.

The effectiveness of lubrication depends, first, upon the adaptability of the lubricant to the surface that is to be lubricated and, second, upon the efficiency of the lubricating devices. The choice of a sui able lubricant for the especial service for which it is required is e ceedingly important in the running of gas motors or any other ki of machinery. Rough, heavy machinery like the axles of hea wagons or carts require a heavy grease or oil, something with co siderable natural body or viscosity. A light oil that flows eas would be pressed out from under the heavily loaded, slow movi axles. Very light bearings on the other hand require a light o and only a very slight amount of it. The oil used for clocks a watches, for example, is of the finest quality and a drop will be suf cient for a whole year. Here we have the two extremes, the slo moving, heavily loaded truck or cart axle and the delicate, light loaded, quick moving watch movement. There is every possible gra of machinery in between and a lubricant exactly suitable for eac It is the duty of the engineer to determine what lubricant is be adapted to the particular machine he is operating and then see th it is supplied in the proper quantities at suitable intervals. Fo tunately, in the case of the gas engine there is not much need f using a variety of lubricants. In general, the oil used to lubrica the piston is good enough for the bearings. Gas engine cylinder o is a mineral oil derived from crude petroleum after the gasoline a kerosene have been distilled off. There are a large number of oil of different densities derived from the same source, ranging fro the light paraffine oils used to lubricate cream separators, guns an sewing machines, to the heaviest grade of engine oil.

These oils are distilled from the residue of petroleum after th more volatile parts have been recovered, beginning at temperatur near four hundred degrees Fahrenheit and continuing above six hu dred. In consequence of the high temperature at which they a volatilized they are especially suited for piston lubrication. Th resist the heat of the cylinder and effectually lubricate the cylin walls, exposed though they are to such high temperatures. Whi the heat of the gases at the moment of highest cylinder pressure well upwards of two thousand degrees, the cylinder walls never rea any such temperature, consequently cylinder oil that will not vapo ize at lower temperature than four or five hundred degrees is high enough grade for the average gas engine. Some of the hi compression engines and some air cooled engines will do better wi a higher test oil but none need go above a burning test of six hundr degrees.

Ordinary animal or vegetable oil is unsuited for gas engine us Some grades may do very well up to temperatures of two or thr hundred degrees but above this it decomposes with the heat, brea ing up into chemical groups that have no lubricating value and some of which, in fact, are positively detrimental to the bearing surface. Lubricants from animal sources, when decomposed, yield stearic acid, which attacks the metal, while vegetable lubricants contain another acid equally as deleterious. Mineral oil does not naturally contain an acid but if not carefully manufactured some of the acid used in purifying it may remain to cause trouble to the user.

Certain animal and vegetable oils are excellent lubricants for places where the temperatures are moderate, but for the cylinders of gas engines and high pressure steam engines mineral oil is used exclusively. For gas engine cylinders a pure mineral oil is necessary while for steam engines there must be a small proportion of either animal or vegetable oil used, usually from four to six per cent to make it spread smoothly over the wet surface. A pure mineral oil is worthless for a steam engine cylinder because it will not form an emulsion with water.

The objection to using a very high fire test oil in a gas engine cylinder is that it will not vaporize readily and the very small portion which finds its way inevitably into the combustion space will not readily vaporize and burn.

LESSON XXVII.

The function of lubrication is to reduce the force of friction to a minimum. It prevents the metal parts from contact with each other and interposes between a film of oil. Fluid friction is, therefore, substituted for dry metallic friction. It is much less and the replacement of the heated oil constantly prevents undue heating of the metal which is so fatal to any machine. Since, therefore, friction and lubrication are so closely bound together, it is necessary to give some attention to the laws or principles relating to friction in order to know best how it may be overcome.

An examination of any metallic surface with a high power microscope will reveal the fact that it is not true, but is, on the contrary, made up of humps and hollows. The very finest and best finished surface is not true. In fact, we have no means of making a perfectly true surface. The depth of the depressions varies with the different kinds of material used in making the surface and the heat treatment to which the metal has been subjected. Very hard material may, with proper care, be made truer than a softer and more granular metal.

If two dry metallic surfaces are held together with an appreciable amount of pressure, the protuberances of the one sink into the hollows of the other and in sense interlocking takes place. The object of the lubricant is to fill up the depressions in both and prevent interlocking. The rougher and larger the surface, therefore, the heavier must be the lubricant; it must have a greater degree of viscosity in order to perform its proper function.

The interlocking of the surfaces prevents motion by interposing a force that acts tangentially to the contact surfaces. Besides this there is another force to be reckoned with. It has been found that two flat surfaces can be made so nearly true that they will hold together with force enough so that if the upper one is lifted, the lower one will adhere also and with a force about two and a half times as great as atmospheric pressure. This shows that it is not atmospheric pressure alone that presses the two surfaces together, but another force which has been named adhesion. It therefore follows that no matter how carefully surfaces may be fitted together nor how true they may be, it is impossible to prevent them from adhering and making it necessary to use force to set them in motion. This force, too, must be constantly applied or motion will cease, since there is always present a force that resists movement. It is also true that fluid friction, with a suitable lubricant, is less than the force of adhesion of metal surfaces.

Friction is not an evil in every case even though it requires much energy and no inconsiderable expense to overcome it. It is necessary in most every machine. For example, the transmission of power by belts depends upon the friction of the belt and the pulley. When a brake is applied to a machine we utilize the force of friction in a useful way. A person could not walk on a frictionless surface because we depend upon the friction of our feet against the surface upon which we walk in order to push ourselves forward. It is the slight amount of friction our feet meet with on smooth ice or upon a waxed floor that makes it so difficult to walk.

Wherever friction has to be overcome in any machine, work must be expended, and, since work produces heat, it follows that the surfaces will heat. The less the friction the less the amount of work that need be expended and consequently the less the heating. A well lubricated bearing, therefore, will not heat dangerously. Besides, the oil that is evaporated carries away a portion of the heat while that which runs off carries away another portion.

Experiment also shows that there are two kinds or, perhaps we had better say, two degrees of friction, the friction of rest and the friction of motion. The former is sometimes called static friction. It is greater than the friction of motion. For example, it requires a greater force to set a body in motion than to keep one in motion.

s because in motion the interlocking action of the parts does ıve time to take place, for one thing, and the weight of the g part does not have time to force out the film of oil from be- the two, for another.

ıll treatises on friction we run across the term, "Coefficient of n." This may be defined as the ratio of the force required to e motion to the force holding the surfaces in contact. In words, if the force holding two surfaces together is ten pounds ; requires a force of two pounds to move one of them, then the ient of friction in this case is two-tenths or twenty per cent.

rules, laws and formulas have been devised to calculate the nt of friction with different kinds of bearings or surfaces but ıre all more or less approximations and of interest chiefly to the ıer rather than to the operating engineer.

amount of friction varies with the different metals in contact. ie shows that the coefficient of friction with brass on cast iron s from .21 to .23; wrought iron on wrought iron from .25 to wrought iron on cast iron from .28 to .38; steel on cast iron .30 to .40, where the surfaces are unlubricated. With lubri- surfaces these coefficients are reduced often to one-tenth of one ent for journal friction.

has been found by experience that for heavy loads the best s can be obtained with a bearing metal of some softer material the journal. Steel journals running in babbitt or bronze bear- give excellent results and are used widely for gas engines and ır machinery. Where the speeds are high and the pressures rate, hard steel journals and hard steel boxes are often used, but ch a case the workmanship should be of the highest grade in to obtain satisfactory results. In machine tools it is common ıd hardened steel bearings running in bronze bushings. This s a good combination for light high speed service, but as before, orkmanship should be of the best. The most common, and for dinary work the most satisfactory combination, is a soft steel running in a babbitt or bronze bearing. In case of damage haft will be damaged least and the bearing is easy to repair. coefficient of friction is not high if the bearing is scraped to a good surface and the amount of work required in making a nably good fit does not make the machinery expensive.

LESSON XXVIII.

bricants naturally fall into three classes, viz.: oils, greases and ı. As regards their origin they may be either animal, vegetable or mineral. Each of the different classes is a suitable lubricant for the purpose to which it is especially adapted. For bearings, either a grease or an oil may be used with good advantage. If the bearing is a heavy, slow speed bearing, where the journal pressure is high, one of the greases is the most satisfactory, and the heavier the load on the journal the heavier should be the grease. For light, high speed journals, on the contrary, an oil will give better service. It does not matter very much whether the oil or the grease is of animal, vegetable or mineral origin provided it is adapted to the purpose intended. All are good lubricants.

The animal oils suitable for lubricants are: tallow, lard oil, whale oil, certain fish oils, and sometimes horse oil. Among the vegetable lubricants we find: colza oil, rape seed oil, olive oil, palm oil and castor oil. Castor oil is the only one suitable for heavy journals, the rest are good lubricants for light machinery. Such rapidly oxydizing oils as linseed oil should never be used. The mineral lubricants include the various petroleum oils, graphite, soapstone and mica. Of all the classes mentioned, the oils derived from petroleum find the widest application. In the first place, they are comparatively cheap, they can be adapted to every use where a lubricant is required, and their lubricating value is satisfactory.

In gas engine practice these oils meet every requirement. They may be used for both the bearings and the cylinder. Even in steam practice the base of all cylinder oils is now of petroleum origin. The specifications for the United States Navy for oil to be used for marine machinery read as follows:

"1. Must be a properly compounded oil to form a homogeneous compound that will not separate under varying temperatures, and must consist of a pure mineral oil, and not more than thirty per cent nor less than twenty per cent of suitable non-drying fixed oils as may be best suited for lubrication.

"2. The compounded oil must be free from rosin, tar, drying oils, sulphur, asphaltic or tarry bodies, soaps or oil thickeners, water, grit, dirt or other suspended matter; and must be free from mineral acid, and must not contain more than two per cent of free oleic acid. The specific gravity to be between 0.915 and 0.927 at sixty degrees Fahrenheit."

There are other tests, but the above will give an idea of what should constitute a reasonably good oil for ordinary service. In addition to the above it is required that the oil stand a flashing test of four hundred degrees Fahrenheit and a cold test of thirty-two degrees. In the cold test, the regulations say the oil must flow at that temperature.

For heavy steam engines, the United States War Department specifies that where lubrication conditions are severe, the oil shall be a compounded oil consisting of five per cent pure acidless tallow oil and ninety-five per cent pure mineral oil. It must be free from acid, alkali, tarry or suspended matter, must not flash below five hundred forty degrees Fahrenheit; must not burn below six hundred degrees Fahrenheit; must not give an acid reaction on polished copper in twenty-four hours and must not contain enough water to cause it to bump or froth when heated in a flash cup.

The object of the tallow oil in steam cylinder oil is to cause the oil to spread evenly over a wet surface. If the same oil were used in gas engine cylinders the tallow would decompose and form a free acid that would eventually attack the cylinder walls. The same specifications hold for gas engine cylinder oil with the exception that it must be a pure mineral oil.

There is perhaps no product bought by engineers that is so frequently adulterated as oils, and there is no way by which the ordinary engineer can guard against being defrauded in the purchase. The tests are difficult to make in most cases and require the services of a good chemist. The farm trade, especially, has been found very easy for the oil adulterators; cheap oil, often of the worst possible quality, has been sold at high prices and the results in most cases have proven disastrous. This is especially true where a compounded oil is used for lubricating the cylinders of steam traction engines. Perhaps the greatest amount of trouble through leaky valves, scored cylinders and overheated eccentrics has been caused by using a very poor grade of oil. Much of the oil contains a free acid and this causes a roughening of the polished surfaces and often corrosion of the cylinder and steam chest studs.

Another thing, most of the cylinder oils are treated with a thickener, usually a mineral soap which has no lubricating value in itself, but which gives the oil body and makes it feel thick and greasy. Gas engine cylinder oils are not adulterated as much as steam engine cylinder oils, but even they are treated occasionally with thickeners.

When we come to greases we find even more adulteration than in the oils. As an example of the kind of adulteration practiced and the method of detection we are reproducing herewith a few tests recommended by Professor G. W. Lewis and first printed in the American Machinist.

"There are two general types of greases: the so-called mineral, and the animal or tallow greases. Mineral greases should be made from a high grade refined petroleum oil and so treated that the least possible amount of foreign substances be used to bring it to a solid state. Lime soap is generally used and the mixture emulsified by mechanical stirring or blowing air through the mixture. Some manufacturers use resin, resinous oils, graphite, soapstone, wax, talc, powdered mica, and asbestos, which are introduced into the grease for the purpose of creating an artificial body.

"Tallow greases should consist of some hard animal or vegetable fat, such as tallow, with a small amount of mineral oil."

Here the mixture is solidified by the use of a soap, in this case a potash soap being usually used. The melting temperature of tallow grease is from fifty to seventy-five degrees lower than the melting temperature of the mineral grease. Some very inferior greases are made from the oils which are the waste of soap factories and sewage disposal systems.

"All greases look good when the can is opened and nearly all will work well on a bearing for a short time, and then a poor grease will cause the bearing to heat, which decomposes the grease into oil and soap, especially if the per cent of soap is high, and impurities have been used. Any adulterants used continually accumulate in the bearings as the grease melts away, and cause gumming and sometimes scoring of the bearing.

"The consumer, to protect himself, should make the following simple tests on any grease he contemplates using: test for acids, alkalies, volatile matter, filling, water and gumming.

"The test for free acid is best made by melting a small quantity of grease and applying blue litmus paper. The test for alkali is made in the same way by applying red litmus paper.

"The test for volatile matter, such as naphtha or benzine, is made by heating a measured quantity to one hundred fifty to two hundred degrees Fahrenheit and determining by weight the amount volatilized.

"The test for filling, or the amount of soap or other material used to form a body, can be partially determined by melting a test tube of the grease to a liquid state and noting the amount of residue or cloudiness in the bottom of the tube, which gives an idea of the amount of soap or other material used in bringing the grease to a solid state. A more accurate test is to take a small sample of grease and dissolve in gasoline, then add phosphoric acid in alcohol solution and if any soap is present, it will precipitate and give a relative idea of the amount in the grease.

"To determine the amount of water in the grease, and to see if it will 'wash out,' place a small amount in a linen cloth or a common handkerchief, fold in the form of a bag, and place in water and knead for five minutes. In this way the amount of water present can be determined and also if the grease will wash out, which is very important, especially in paper making and laundry machines, where water comes in contact with the bearings.

The simplest method to determine the amount of gumming is to e a sherry glass, put in a few pieces of copper wire and add con trated nitric acid, then add the grease in finely divided particles he solution, and stir until all the grease has been broken up. In case of a tallow grease, the tallow will form a solid crust on top he liquid in about an hour; with a vegetable oil, the oil remaining be about the consistency of butter, while with a mineral oil, the remains in a liquid state. The blackish substance that appears w the oil represents the impurities that cause gumming of the ring. Next separate the acid from the oil and the black substance add gasoline to the latter two. This washes out the oil and separates the gumming substances so that a fair idea of the quantity in grease can be obtained."

LESSON XXIX.

ome crude petroleums found in the United States, notably those ined near Mecca, Ohio, in Erie County, Pennsylvania, Chatha n, West Virginia, and Monticello, Kentucky, can be used for lubrica ng purposes with very little preparation. The oil is allowed to le in tanks to get rid of the water and solid particles and then is ted in a still to get rid of the volatile constituents, after which it hered through charcoal. [illegible] are sold under a variety of trade names [illegible]

ylinder oils are [illegible] grease, the [illegible] difference [illegible] consistency [illegible] is dependent upon the [illegible] light colored [illegible] ing through charcoal. [illegible] is obtained [illegible] metallic means. [illegible] then settling [illegible] degrees Fahrenheit [illegible] ten gallons [illegible] degrees Fahrenheit [illegible] of oil will [illegible] aluminum [illegible] purpose

None of these thickeners have any lubricating value, neither are they, as a rule, much detriment to lubrication. Under certain conditions, moreover, they may be an aid to correct distribution. The purpose of thickness is, of course, to deceive and for that reason the practice cannot be defended.

Nearly all the mineral oils are of the same viscosity when heated to a high temperature, consequently there is a growing tendency to use light oils. This is especially desirable in winter when the cold has the effect of congealing the oil and making distribution uncertain. These thin cylinder oils, if of the right flash test, seem to work just as well in summer, and are being used more and more each year. A good gas engine cylinder oil should flow full and clear and not contain lumps of heavy oil. For all ordinary engines a flash test of from 450 to 550 degrees is ample. Engines that work under heavy load for long periods and whose cylinders get very hot may require a higher test oil.

In judging the purity of an oil and its suitability as a lubricant, the following tests are made. These tests require special apparatus and the services of a chemist and can be available only to heavy users of oil. They are inserted here merely as a matter of interest.

1. Specific gravity test.
2. Alkali test.
3. Sulphuric acid test.
4. Free acid test.
5. Viscosity test.
6. Flashing point test.
7. Evaporation test.

The first test determines the weight as compared with an equal volume of water, and may be made in a variety of ways, but the most common method is by the use of a hydrometer. The test itself is of little value except possibly as a method of identification.

The second, third and fourth tests are very important as either alkali or acid in any considerable quantity will attack the metals with which it comes in contact. It is claimed that if an oil contains as much as three per cent of free acid and if left in contact with brass for twelve hours it will have acquired a green color. This is a rough test easy to make.

Viscosity is of importance as determining the body or greasiness of the oil unless thickeners have been used. It is usually made with special instrument called a viscosimeter and under standard contions of temperature, oil head, etc. A rough comparative method to place several drops of each of a number of samples of oil on a plate, then elevate one end of the plate and observe the relative of flow.

The flashing test is easy to make. The oil is heated in a suitable p, in which a thermometer is hung and at intervals a lighted taper passed across the top of the cup. When the vapor takes fire—ies—the temperature is read. If heated a little higher, the sur- e of the oil will catch fire, when the burning temperature may be d. This is an important test. It shows the suitability of an oil r cylinder purposes. An oil of too low test will "crack" in the inder and form a carbon deposit.

The evaporation test is also simple. It consists in weighing out given sample of oil and keeping it at a temperature of 212 degrees r twenty-four hours and weighing again to find the loss in weight. good oil should not lose more than five per cent.

Elaborate machines have been devised to test the lubricating value oils in which the speed of the journal and the load it supports can varied at the will of the operator. The machines are of value in ermining the relative lubricating values of oils or greases, and used in laboratories devoted to testing materials.

There are many recipes used in manufacturing oils and greases, d many different brands and grades are made for different pur- es. The following are a few samples of grease recipes taken at dom from "Lubricating Oils, Fats, and Greases," by Hurst:

Mica Grease.—Fifty pounds rosin oil, fifty pounds Scotch shale , twenty pounds French chalk and twenty pounds of slaked lime red together.

Axle Grease.—Melt together fourteen pounds palm oil, twenty-two nds anthracene oil, ten pounds rosin oil, and one pound of soap, ping the mixture heated until a clear, transparent mass is ob- ned, then allow to cool.

The best grades of greases are made of good stock and are carefully pounded. They are suitable for and widely used on machinery rings. Large quantities are used for the crank bearings of gas gines and prove highly satisfactory. Care must be taken, how- r, to obtain only greases of good grade.

LESSON XXX.

The nature of the part requiring lubrication, the conditions under ich lubrication must be performed and the character of the lubri- t employed, all must be considered in selecting the oiler or oiling tem. All of the sliding or rotating parts of a gas engine require tinuous lubrication and some device must be selected that will be tain and continuous.

To be most efficient the lubricator should be adjustable so t can be set to deliver a definite quantity of oil every minut must be certain in action and never deliver either too much little oil. Too little oil will cause overheating of the part damage to the motor; too much oil is wasteful and, in some ca for example in the cylinder, will cause much trouble. Carbo form in the cylinder, the spark plugs wi come fouled and the piston rings will sti their grooves. No such damage is liable to on other parts of the engine, but an over s of oil makes a dirty engine and this is lia cause trouble. An over supply of oil on the bearings usually results in oil running o the fly wheel and being thrown off by fugal force and smearing everything in th mediate vicinity with oil.

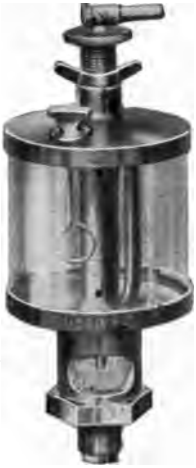


FIG. 25. SIGHT FEED OILER.

An oiling device should be as nearly as ble automatic. It should measure out ar liver the lubricant at a regular rate of fl matter whether it be cold or warm, thick o It should not be affected by weather cond and should not require frequent adjus When the engine runs faster it should deli a little faster and when the engine runs sl flow of oil should be automatically reduced. is true particularly as regards cylinder lu tion in variable speed motors and mak selection of a suitable lubricator a matter of grave importance. oiling of the crank bearing is the next most important membe after that the main bearings.

Slow speed stationary gas engines can be lubricated without difficulty and with very simple apparatus. An ordinary sigh oiler will answer very well for the cylinder, and a hard oiler or cup for the main bearings and crank. It is true that these d are not truly automatic, they are not positive, they require fre adjustment and they are affected by changes in temperature; y indoor conditions where there is an engineer in attendance the be made to work with a fair degree of satisfaction on slow spe gines. Moreover they are inexpensive.

They are not sufficient for high speed motors like those us automobiles, motor boats, tractors, locomotives, aeroplanes, et motors of this class some one of the many oil pumping syste the market must be selected. There has been as great developm stems of lubrication within the past dozen years as in the motors mselves. In fact, the motor of today depends as much upon the ciency of the lubrication system as upon the reliability of the ition system or any other accessory. This being the case we shall dertake to describe the leading systems in general use, beginning ith the simplest.

Sight Feed Oilers.—The simplest oiler used to lubricate gas engine linders is the sight feed oiler shown in figure 23. On horizontal gines this type of oiler screws directly into the upper side of the linder, while on vertical cylinders a connection is made by means of an elbow and ort nipple which permits the oiler to stand a vertical position. The oil is contained the glass body from which it passes to e central hollow spindle through the openings shown. Inside this spindle there is a re screen enclosing a needle valve which ts in a conical seat [illegible] ce by a helical spring in the upper portion of the tube. There is a [illegible] the cap which when [illegible] ts the needle valve. The amount of oil passing between the valve and its seat is ulated by the milled head [illegible] e winged [illegible] m. Below the [illegible] ss shows how fast the [illegible] is kind of oiler [illegible] n the engine is stopped [illegible] [illegible] t. It is liable to clog [illegible] ding at any moment [illegible] n is liable to form in the [illegible] the bottom. This will [illegible] ss. It is most liable [illegible] part of the charge [illegible] through the oil [illegible] ges.

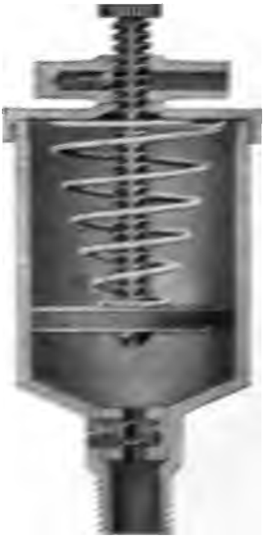


Fig. 23. [illegible]

Figure 24 shows a [illegible] ler. The oil [illegible] ove. In filling the [illegible] ns compressing the [illegible] p. The [illegible] grease. When the cap is screwed back in place and the thum unscrewed a few turns, the spring is released and presses th down with considerable force on the grease. Below the rese will be observed that there is a small screw with a hole drilled which can be turned to register either partly or fully with th ing from the reservoir. By adjusting this screw, the rate of oil can be quite accurately regulated. When the engine down, the pressure on the piston must be removed by screwin the thumb nut. This type of oiler works very satisfactoril great many places.

LESSON XXXI.

Hard oils or cup greases are excellent for the main bear crank bearings of slow or medium speed engines, but not suit the cylinder or for the bearings of automobiles and very hig motors. The cylinders must have a liquid oil and thi be delivered at regular intervals exactly the right quantity. If to is delivered, the spark plugs fouled and the fuel mixture will riched. The result will be dense of dark smoke at the exhaust, ca tion of the cylinders and lack of If not enough oil is supplied, th der will overheat, the walls of th der and the rings may be scored engine ruined.

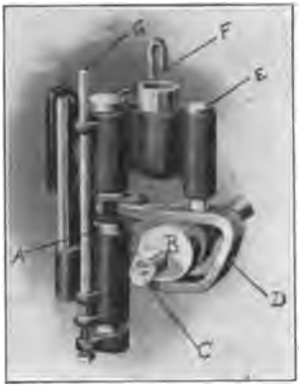


FIG. 27. ONE OF THE OIL PUMPING UNITS.

There is, moreover, only a re small margin between insufficie too much lubrication for the cy This necessitates the use of some that will measure the oil accurat deliver it at the point where it i used in the correct amount. It also deliver the oil at consi pressure and the pressure should increase with the sp the motor. This has been amply demonstrated in the man mobile races, especially the long distance races where excep high speeds are maintained. The only kind of lubricator t these exacting requirements is some form of pump which is by the motor it lubricates and thus varies its speed of oil in exact proportion to the speed of the piston. A pump or lubricator, moreover, is not affected by climatic changes, by p of dirt or carbon and if built right can be made to deliver oil at a more uniform rate than any of the gravity oilers no matter how well constructed. Furthermore, when the motor stops, the flow of oil stops automatically and starts again when the motor starts.

There are quite a number of good oil pumps on the market and no attempt will be made to distinguish between the relative merits of the different machines. We shall, however, endeavor to describe several in an impartial manner merely with the thought of giving the reader an idea of the various mechanical principles involved in oil pump construction. The first one we shall take under consideration is the Madison-Kipp oil pump.

Figure 27 shows one of the units which go to make up one of these outfits, while figure 28 shows the manner in which the various units are combined in the complete outfit. These pumps are built in a variety of styles with any number of feeds from two to twelve. Each feed requires a separate unit to do the pumping and a separate delivery pipe but all are driven from the same drive shaft, as will be presently described. Furthermore, the rate of delivery for each feed may be regulated independently and the amount of oil delivered can be seen through the sight feed glass. In figure 28 it will be observed there is a partition across the main reservoir, making it possible to use two different grades of oil, one for the cylinders, the other for the bearings and have both delivered by the same pump. It may be well to observe in passing that not all of the pumps are provided with two compartments but two may be obtained if so ordered.

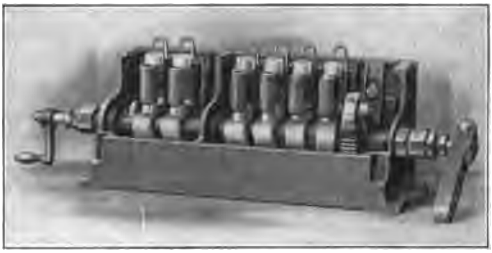


FIG. 28. ARRANGEMENT OF PUMPING UNITS. NOTE PARTITION IN RESERVOIR FOR TWO KINDS OF OIL.

The pumping unit shown in figure 27 consists of a plunger, A, driven by a cam, B, which is mounted on the cam shaft, C. Motion is transmitted to the cam shaft by means of a ratchet crank which is actuated by any convenient reciprocating member of the engine as can be seen by referring the figure 28. The cam, B, is enclosed by a yoke, D, one end of which is attached to the pump plunger while the opposite end is guided by the fulcrum pin, E. The cam is provided with a special groove into which a pin located in the top of the yoke, D, engages, thus giving a rotating motion to the pump plunger, A, as well as a vertical motion. The oscillating motion of the pump plunger is made necessary because no check valve or valves of any kind are used in this pump. Instead, the lower part of the plunger is slotted and this slot registers on the suction stroke with a suitable opening in the side of the pump barrel, thus allowing the oil to enter the pump chamber. On the downward stroke, the plunger rotates and shuts the opening between the pump chamber and the reservoir and at the same time opens another slot to the delivery pipe. The oil is then forced out through the goose necked pipe, F, which can be seen through the sight feed glass. From the upper reservoir into which pipe F delivers, the oil is taken and delivered to the motor by an exactly similar pump plunger which, as can be seen in the illustration, is merely an extension of the lower plunger. A regulating screw, G, operates a sleeve which graduates the delivery opening in the lower pump barrel so that any portion desired of the oil may be delivered back to the main reservoir, while the remainder is forced out through pipe F to be used either in the cylinders, bearings or other part of the motor. The plunger is made of hardened steel, accurately ground and lapped to a perfect fit in the cast iron pump barrel.

Any of the pumping units may be taken out and replaced without disturbing any of the other units in the tank and without taking down any of the piping other than that attached to the pump in question. The oil pump reservoir is covered with a close hood which not only protects the oil from dust or rain but enables the operator to observe the flow of oil from each unit through the window provided for that purpose. No adjustment is necessary for changes in the weather or for using a light or a heavy oil.

LESSON XXXII.

Force feed systems of lubrication may be operated either by pump feed or by compressed air. The former is positive and the pressure is usually high, thus insuring positive and thorough lubrication. The latter usually works with less pressure than pumping systems and for that reason is not as positive. There are some systems of compressed air lubricators, however, in which the pressure can be varied and which automatically increase the pressure with the speed of the motor. These systems are said to be quite satisfactory in operation. In all the compressed air lubricating systems air is compressed in the oil reservoir and causes the oil to be delivered through a pipe which leads from the bottom of the reservoir to a mainfold from which pipes are run to the different points of lubrication. In one two cycle engine there is a pipe leading from the crank case to the compression chamber, consequently the compression in this chamber is the same as in the crank case, or about five pounds, provided the crank case is air tight. This is sufficient to force thin oil to the cylinders and bearings, but not enough if the weather is cold or if the oil is heavy. There are no compressed air systems, moreover, that are able to deliver semi-solid oils or greases with the same certainty as plunger pumps. In this field of engineering notable improvements have been made within recent years.

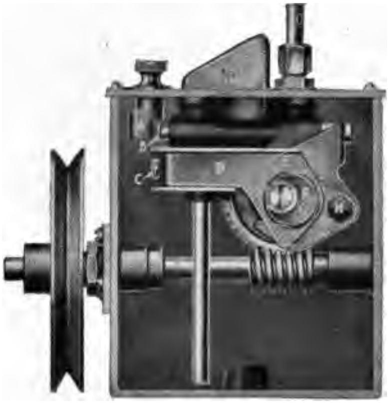


FIG. 29. SHOWING DRIVING MECHANISM OF ONE OF THE DRIVING UNITS.

One of the leading types of oil pumps used widely on tractors was described in the last lesson and in this lesson we shall describe another which is built by the Detroit Lubricator Company. The working parts of this device are shown in figures 29 and 30. Figure 29 shows a single unit pump complete, with the side cut away exposing the interior. A number of these units may be assembled on the same base and pump from a single oil reservoir if desired. It will be noticed that a shaft, on which a worm is mounted for each pumping unit, passes through the walls of the reservoir. This shaft receives its motion from some rotating element of the engine by means of a belt working over the grooved pulley on the left. The worm mounted on the shaft operates a worm wheel which in turn drives the pump's plungers through two eccentrics, as can be seen by referring to figure 30.

In the drawings these eccentrics are labelled F and G respectively. Eccentric G drives the piston B through the bell crank yoke E. This piston lifts the oil from the reservoir through the vertical tube shown in figure 29 and it discharges it from the nozzle at N. The amount of oil discharged may be regulated by the milled screw shown on the cover. This screw is provided with a cam, A, below the cover, which regulates the throw of the piston B and this regulates the amount of oil discharged.

The other plunger, C, takes the oil from the pocket in the sight feed chamber where it is delivered by plunger B, and forces it to the point of application, through the tube O shown on the top of figure 29. Plunger C is actuated by eccentric F, through yoke D. The straight yoke D and the bell crank yoke E cause the pistons to work alternately. Each is practically at rest while the other is traveling most rapidly. Advantage is taken of this peculiarity of motion to construct a valveless pump. A port is provided in each piston which controls the passages to the other so that each plunger is in practice a mechanically operated valve for the other.

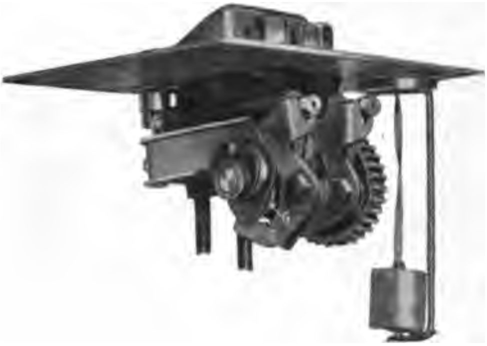


FIG. 30. ANOTHER VIEW OF THE WORKING MECHANISM.

The eccentric, G, is driven by its mate, F, and occupies the same relative position on the shafts when the engine is running forward. When the engine is reversed it slips on the shaft and comes to rest just opposite eccentric F, where it again begins to operate the plunger B. In this way the oiler automatically adjusts itself to deliver oil regardless of which direction the engine runs.

This pump, like all others, will stop feeding oil when the engine stops and begins again just as soon as it starts up.

In this respect it is less troublesome than the compressed air lubricators, which will keep on feeding after the engine stops unless the air pressure in the oil reservoir is relieved.

The two pumps which have thus far been described are of the valveless type in which ports in the piston are utilized instead of moving parts. There are, however, a number of other good pumps on the market in which check valves are made use of, usually of the ball type. Whether or not there is any material advantage in valveless pumps over those with valves we shall leave to the reader's own judgment.

CHAPTER X.

SPARK PLUGS AND MUFFLERS.

LESSON XXXIII.

A spark plug is one of the elements of a jump spark ignition sys-em. One of the secondary wires of the jump spark coil is attached o the center terminal of the spark plug, the other goes to the engine rame. The secondary or induced current passes to the plug, thence ownward into the cylinder, where it jumps across the engine frame y way of an easy path provided in the plug itself. he distance the current jumps should not be greater han one-thirty-second of an inch nor less than one-ftieth. The rule is to adjust the points so that their distance apart shall not be more than the thickness of a dime. If the distance is greater the current will fail to jump and no spark will be formed.

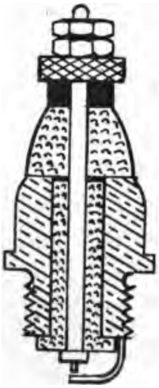
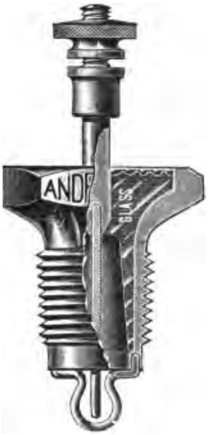


FIG. 31. A CRUDE FORM OF CHEAP PLUG.



IG. 32. SPARK PLUG ITH GLASS INSULA-ON.

In the make and break circuit which is of low voltage, the points are brought together inside of the cylinder by mechanical means, thus closing the circuit and permitting the current to flow. When the latter is suddenly interrupted by the separation of the points an arc is formed which ignites the charge. In the jump spark system the circuit is never completed, but the voltage is made so high in the coil that it can easily jump the small gap at the points of the plug.

Troubles with motors missing are frequently due to a dirty spark plug, caused by a deposit carbon or of carbon and oil between the points. Carbon is a good nductor of electricity, and if it forms in the plug, making a con-ection between the center terminal and the metallic shell at any int, the current will follow the carbon instead of jumping across the points as it should. Carbon alone, or oil with much carbon in it, will have the same effect. For this reason the best spark plugs are constructed in such a manner that plenty of room is provided and double air spaces between the central electrode and the shell to prevent fouling. One fact must never be lost sight of with the jump spark splugs and that is, we are dealing with very high voltage electricity with voltages running from 20,000 to 30,000 volts and insulation must be as nearly perfect as ingenuity can devise, otherwise there will be a leak of current to the frame and no spark will be formed at the points. The two great causes for faulty ignition, therefore, are either a dirty plug or broken insulation. If the plug is dirty it can be cleaned with gasoline and a brush, though the better liquid is hydrochloric acid. Most people use gasoline and it serves the purpose well enough.

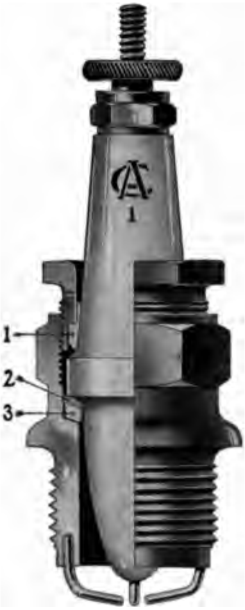


FIG. 33. SPARK PLUG WITH PORCELAIN INSULATION.

In order to determine if a spark plug is in working order, take it out of the cylinder, connect up the wires, then lay it on some clean metal part of the frame, like the rim of the fly wheel, with the metal shell only in contact therewith, and turn on the current. If the sparks come out in a stream it is all right, but if they jump intermittently, the plug needs cleaning. If they do not jump at all, it is a pretty good indication that the insulation is broken down at some point, that is, provided you are sure that the source of current, the coil and connections are in working order.

While outwardly spark plugs look much alike, there is a wide diversity in the details of construction.

Figure 31 represents a rather crude form of cheap plug. It consists of a metal body which screws into the cylinder, having a wire terminal fastened at the bottom and curved around to almost meet the central electrode. This latter passes upward through a porcelain insulator and through two asbestos washers, which show black in the drawing, and is held in place by a lock nut. The asbestos washers act as cushions between the porcelain and between the lock nut and the upper porcelain. One of the ignition wires is attached at the top of this central electrode, the other somewhere on the engine frame.

The spark is formed at the bottom between the curved wire and the central electrode. The porcelain and asbestos act as insulators, and as long as the latter is not cracked, it serves the purpose admirably. There are few better insulators than porcelain, and since it is cheap and easy to mold, it is used extensively in spark plugs.

Mica is also used, but it is not as good because, being formed of a large number of thin sheets, it affords many places where oil and carbon can penetrate and lead the current to the outer metallic shell. It has this advantage, however, that it is elastic and not easily broken. It is used to a considerable extent, but not where conditions are severe. It is, moreover, injuriously affected by the heat of the motor. Glass is a good insulator and is used to a limited extent.

Figure 32 shows a plug with glass insulation which is absolutely moisture proof. It possesses the added advantage of a window which shows if the spark is being formed as it should be.

Figure 33 represents another type of plug having porcelain insulation. Referring to the figures: 1 is a brass collar with the inside turned the same taper as the porcelain and pressed into place. This collar has an outside shoulder which fits the bushing so if there should be any variation in the porcelain there is no chance of tightening the plug wrong. No. 2 shows a copper asbestos gasket and No. 3 a steel washer. In tightening, the porcelain revolves both the gasket and steel washer and the latter polishes the bottom of the shell and forms a joint. It will also be noticed that there is no place between the terminals where carbon can collect and cause a short circuit.

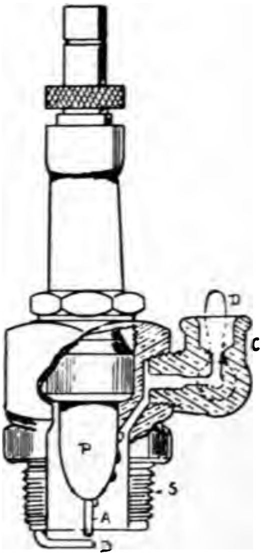


FIG. 34. A PRIMING PLUG.

Figure 34 illustrates what is known as a priming plug. By turning the handle D upwards, as shown in the cut, gasoline can be squirted into the cup at C from whence it runs down to the terminals and forms a rich, easily ignited mixture where the spark is formed. When no provision is made for priming cups on a motor this style of plug is very effective.

Spark plugs are made in a number of different sizes. There is the standard A. L. A. M. plug three-quarters of an inch in diameter with eighteen threads per inch; the one-half inch pipe-size plug .84 of an inch in diameter with fourteen threads per inch and a plug of .7 of an inch in diameter with seventeen threads to the inch. This is the French or standard metric thread.

There seems to be no good reason why there should be such a variety of sizes and it would be better if one size should be adopted, at least for all automobile and stationary motors.

In general, the higher priced plugs are better constructed and are worth the additional price. The points of the best plugs are made either of platinum or of an alloy of platinum and iridium. The shanks of plugs, or the parts that screw into the motor, are made of different lengths to accommodate different thicknesses of cylinder wall and water jacket. The best results are said to be obtained when the points are just flush with the inside of the cylinder head.

LESSON XXXIV.

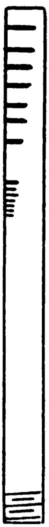


FIG. 35.

When a column of air is set in rapid vibration it acts in some way upon the auditory nerve in the ear and transmits a sensation to the brain which we call sound. Anything that sets the air in rapid vibration is sufficient to produce sound, as for example, the striking of a bell, the twanging of a violin string or the sudden escape of gas under pressure. The same causes which produce sound under ordinary conditions will not do so in a vacuum, simply because there is no medium to transmit the vibrations. The volume and pitch of sound depend upon the volume of air set in motion and the rapidity of its vibration. Sound waves travel somewhat in the way waves travel in water. They extend outward in all directions from the center until they finally become so faint at a distance from the source that the ear cannot recognize them. In the transmission of sound the air is set in motion almost like the surface of still water when a pebble is tossed in. The water does not flow from the center; there is only a wave-like disturbance, a short to and fro motion, and this is much the same as happens in air when sound waves are generated.

The loud report of a gas engine or of a gun is due to the concussion caused by the high velocity gases suddenly striking the relatively still air. In order to prevent the loud barking of an engine, therefore, or the report of a gun, all that is necessary is to reduce the velocity of the exhaust gases before they find free egress to the atmosphere. If that can be done there will be no noise.

If gas engines could be so designed that the gases were expanded down to atmospheric pressure in the cylinder, there would be almost no sound when they were allowed to escape to the atmosphere but, as is well known, this is not practical. Consequently, in most engines the exhaust valve opens when the pressure is at anywhere from twenty to sixty pounds per square inch in the cylinder. In high speed motors of the automobile type the valve opens when the piston is still some distance from the end of its power stroke in order to allow the gases to get away freely and not impede the piston on its return stroke. The result is that such engines have a very sharp, loud exhaust that is objectionable. In order to overcome this, various forms of mufflers have been devised to silence the exhaust.

A muffler could be devised by using a very long exhaust pipe in which the gases would have an opportunity to expand before reaching the outer air. Such a device would not, however, prove satisfactory for automobile use and would be cumbersome, even for stationary engines. Another plan which was used on some small stationary engines a few years ago was to provide an exhaust pipe with slots sawed in it as shown in figure 35. The idea in this case was to allow the gas to escape gradually through a number of small openings rather than to escape all at once in full volume. This arrangement was a cheap makeshift and did not silence the sound sufficiently to fulfill modern requirements.

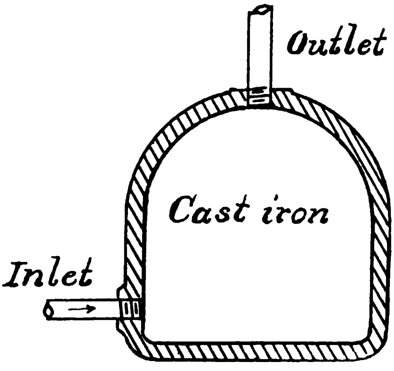


FIG. 36. IRON MUFFLER POT.

Figure 36 shows a simple muffler pot which depends upon expanding the gases in a closed chamber until their velocity is reduced to a point where they will not produce violent concussion on the surrounding air. This device works quite successfully provided the volume of the pot is at least ten times that of the cylinder. The walls of the pot must be made strong enough to withstand the explosion of a charge, for it often happens that a charge is exploded in the muffler and unless it is made strong or provided with a relief valve, considerable damage may be done.

Another modification of the pot principle is shown in figure 37. Here a pit is dug in the ground with walls built up of brick or concrete. The top is covered with planking in which a good sized opening is cut. A length of tile may be placed over the opening and the whole covered over with earth as shown in the figure. The expansion of the gases in the pit and the deadening effect of the earth makes a very effective muffler for stationary engines. The only objection to such an arrangement is that if an unexploded charge enters the pit and is subsequently ignited it may blow the cover off and cause some damage. The writer used such an arrangement for a number of years and experienced such an accident twice, once when the ignition system of one engine of a pair that were working in parallel was out of order and another time when the inlet valve of one of the engines was badly out of order. Had only one engine been working it is not likely that there would have been trouble, but with two working, one engine operated the other that was out of order. It is on account of just such accidents as these that it is never safe to lead the exhaust into a brick chimney.

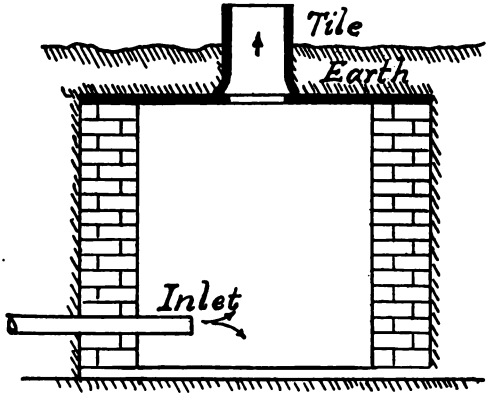


FIG. 37. PIT EXPANSION CHAMBER.

Mufflers used on automobiles nearly always are fitted with a relief valve so if an explosion does occur in the muffler it will not do any damage.

LESSON XXXV.

At the instant the exhaust valve opens, the pressure of the gases in the cylinder, as stated in the last lesson, is from thirty to sixty pounds per square inch and their temperature ranges from nine hundred to twelve hundred degrees Fahrenheit. It is the high temperature that gives the gases their pressure, consequently if they are allowed to escape unhindered into the air they move with very high velocity and cause a sharp report, like the firing of a gun. There are obviously two ways in which the noise may be silenced, either rob the gases of their velocity by gradual expansion or by cooling. Both methods are employed. Automobile engines are equipped with mufflers for slow expansion and many marine engines with mufflers that use water to absorb the heat and thus cause a contraction of the gases. In some of the latter the water is sprayed directly into the gases and in others water is made to circulate around an expansion chamber like the water jacket of the cylinder.

If the exhaust gases were at the same pressure as that of the atmosphere there would not be very much noise to the exhaust. But since it is not possible to carry expansion in an engine cylinder that far economically, the exhaust valve opens while the gases still have considerable energy left. For this reason the remainder of the expansion must be provided for in a chamber outside the cylinder. If the pressure at the end of the working stroke is seventy-five pounds absolute it is quite evident that if they are allowed to expand five times their volume in the muffler and at the same time have their velocity retarded they will be at the same pressure as the outside air and emerge from the muffler with little or no noise. Acting on this priniciple, mufflers are built with a volume of from five to seven or eight times that of each cylinder of an engine. The gases are made to traverse a number of chambers and change their direction a number of times before emerging and thus their velocity is destroyed while at the same time they are gradually expanding. This, then, is the principle employed in all cases. The method of constructing mufflers is shown in the various figures. In all the cases shown it will be seen that the gases have to take a very tortuous path. Figure 41 represents one of the many styles of marine mufflers which employ water.

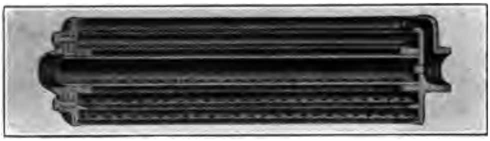


FIG. 38.

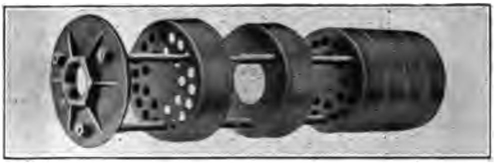


FIG. 39.

There is an impression prevalent that the use of a muffler on an automobile consumes considerable power. This idea is probably true when the engine is running at a very high rate of speed but under normal speeds, tests seem to indicate that the loss is small. In some cases, in fact, there appears to be an actual gain in power due to the formation of a vacuum in the muffler. At least this is claimed by a number of builders of mufflers. In most cases, however, the writer believes a muffler absorbs a slight amount of power but nowhere near as much as many drivers seem to believe.

FIG. 40.

All automobile mufflers are provided with a cut-out which may be operated with a foot lever. The indiscriminate use of the cut-out had led to the adoption of ordinances in a number of cities prohibiting the use of the cut-out altogether. It has, however, a use aside from that of gaining a little additional power that is perfectly legitimate and that is to allow the driver to determine from the exhaust if any of the cylinders are missing fire. This cannot be done while the engine is exhausting through the muffler.

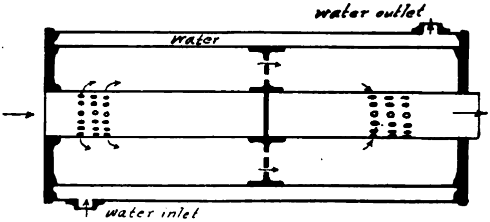


FIG. 41. SIMPLE FORM OF WATER COOLED MUFFLER.

Every automobile muffler is also provided with a relief valve that opens automatically in case of a muffler explosion, thus relieving the pressure and preventing damage.

A muffler should be taken apart and cleaned at least once a year. In constant use it will collect quite a deposit of carbon and grease which in time will clog the openings and prevent its free action.

Automobiles used in winter are often provided with a heating coil to warm the passengers by means of the heat of the exhaust gases. When one considers that practically one-third of the heat of the fuel passes out through the exhaust it is a wonder that more use is not made of this source of energy. A number of plans have been proposed but little has actually been accomplished except now and then the heating of an automobile or the warming of a small room.

LESSON XXXVI.

Gas engines are rated according to their brake horse power at the factory where they are made, and since they are all made at or near sea level they fail to give their rated power when taken to high altitudes. Traction engines used on the high table-lands of New Mexico, Colorado or Montana will not develop as much power as they will in the Mississippi Valley. An engine in an aeroplane that will develop 80- or 100-horse power on the ground in the vicinity of Chicago or New York will gradually decrease in power as the machine rises.

While this is true with regard to all internal combustion engines, the very opposite occurs with a steam engine. A little consideration of the principles of operation of the two motors will show the reason. A steam engine running under say one hundred pounds average absolute pressure and exhausting into the atmosphere at sea level has to overcome a pressure of 14.7 pounds at the exhaust: Its actual effective pressure will accordingly be the difference between the forward pressure and the exhaust pressure, or 85.3 pounds. If this same engine, working under the same pressure, were taken to a high altitude where the pressure of the atmosphere were say only ten pounds, it would show an increase in power, because the back pressure would be reduced from 14.7 to ten pounds. This would be equivalent to adding 4.7 pounds to the forward or driving pressure.

In the case of a gas engine we have an entirely different set of conditions. The charge of fuel is taken into the cylinder by atmospheric pressure. Near sea level where the atmosphere exerts a weight of 14.7 pounds on every square inch, the pressure in the cylinder at the end of the charging stroke is about fourteen pounds in moderately slow speed engines fitted with spring loaded valves. The pressure can never be as great as that of the atmosphere because it requires a slight difference in pressure to open the inlet valve. Even if the valves were mechanically operated, the time during which the piston is drawing in a charge is so short and the opening so small relatively to the bore of the cylinder that the pressure inside the cylinder and outside will not have time to equalize.

In high altitudes where atmospheric pressure is less there will be the same difference between pressures inside the cylinder and outside at the end of the charging stroke. Accordingly, where the air pressure is normally twelve pounds we should hardly expect more than eleven pounds inside the cylinder at the beginning of compression. Air consists of a mixture of two gases, oxygen and nitrogen, in the proportions of one-fifth oxygen to four-fifths nitrogen by weight. This proportion holds good all through the atmosphere from the bottom to